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OHMSETT TEST OF NOFI VEE-SWEEP AND NOFI 600S OILBOOM

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16. Abstract

A NOFI Vee-Sweep and a NOFI 600S Oilboom, both manufactured by NOFI TROMSO A/S of Norway, were tested at the Ohmsett test tank in Leonardo, NJ. The V-Shaped Sweep is an oil boom designed for use with a skimmer at the apex of the V-Shaped configuration. Oil is funneled back to the skimmer by the converging sides of the V and concentrated for more efficient skimming. The 60 meter length of the sweep is doubled over to form the V and held in this shape by cross netting at the bottom of the skirt. The bottom netting is claimed to help stabilize the oil in the sweep. The sweep was towed with a 700mm skirt depth and mouth opening of 16 meters. The mouth opening was reduced from the designed 19.8 meters to fit in the tow tank without causing excess blockage.

The limiting towing speeds of the sweep were determined with and without oil present, in calm water and in small waves. The sweep's ability to conform to waves was also determined. Towing forces were measured. Limited data on oil loss rates were obtained. Testing confirmed the manufacturer's claim that the sweep can be towed at 1.0 and 1.4 knots with oil in calm water, based on the first loss of oil. The critical tow speed was found to be 3.4 to 3.6 knots in calm water.

For the NOFI 600S Oilboom, only towing speed with oil were measured with and without the boom's feather net. The 60 meter long oil boom was towed in a U-Shaped configuration with a mouth opening of 14 meters. First loss and gross loss speeds were 1.2 and 1.4 knots, respectively. The presence of the feather net appeared to increase oil loss speeds in waves by as much as 25%.

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METRIC CONVERSION FACTORS

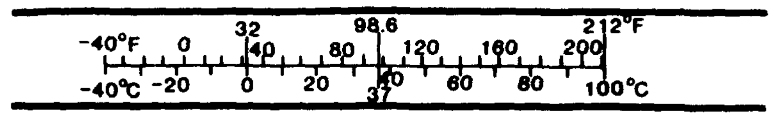
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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The OHMSETT staff also wishes to acknowledge and thank the following persons for their efforts and expertise:

Kaare Davidson representing NOFI TROMSØ A/S who tended to the sweep.

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Byrge Skottvoll representing Bentech Subsea for interfacing the LM 200 oil thickness sensor to the OHMSETT data collection system.

Many people contributed to conducting the tests and writing this report. The project was a team effort. All of the staff at OHMSETT contributed on a day by day basis in the testing. Besides the authors, OHMSETT staff who participated in the testing are listed alphabetically below:

Burrowos H. Aumack
James Z. Butkowski
Kevin McLavish
James H. Nash
John J. Reseter
Robert A. Vitale

EXECUTIVE SUMMARY

A NOFI Vee-Sweep and a NOFI 600S Oilboom, both manufactured by NOFI TROMSØ A/S of Norway, were tested at the Ohmsett test basin in Leonardo, N.J., between August 13, 1992, and October 6, 1992. The U.S. Coast Guard provided the oil booms and funded the tests. The NOFI Vee-Sweep is an oil containment sweep with possible application with the U.S. Coast Guard's Vessel of Opportunity Skimming System (VOSS). The booms were tested to determine if skimming could be performed at speeds higher than the current VOSS limit of 0.75 knots.

The Vee-Sweep is an oil boom designed for use with a skimmer at the apex of the V-shaped configuration. Oil is funneled back to the skimmer by the converging sides of the V and concentrated for more efficient skimming. The 60 meter length of the sweep is doubled over to form the V and held in this shape by cross netting at the bottom of the skirt. The bottom netting is claimed to help stabilize the oil in the sweep. The sweep was towed with a 700 mm skirt depth and a mouth opening of 16 meters. The mouth opening was reduced from the designed 19.8 meters to fit in the tow basin's width without causing excessive blockage. The Vee-Sweep can also be used with a 1000 mm skirt depth but this skirt could not be tested in the Ohmsett basin without large blockage effects.

Tests on the Vee-Sweep included critical tow speed tests to determine how fast the sweep could be towed with no oil present, oil loss speed tests to determine the key oil loss speeds with oil in the sweep, wave conformance tests to measure how the sweep follows waves, and oil loss rate tests to determine how much oil is lost at various speeds above the first oil loss speed. Results of these tests are summarized below:

Critical Tow Speed Tests

- Apex submergence was the limiting factor on towing speed
- A critical tow speed of 3.5 knots was obtained in calm water and small waves
- A critical tow speed of 2.4 knots was obtained in harbor chop conditions
- A total towing force of 8540 pounds was measured at a tow speed of 3.5 knots

Oil Loss Speed Tests

- Tests were conducted with and without a skimmer operating in the boom, with two types of oil and with differenct preload amounts of the heavier oil
- First loss speeds of 1.0 to 1.5 knots were obtained for the heavier of the two oils
- A first loss speed of 1.1 knots was measured with the lighter oil compared to 1.4 knots for the same preload of heavy oil
- First gross loss speeds ranged from 1.3 to 1.8 knots
- Operating a skimmer while towing had little effect on the results
- Larger preloads reduced first loss and first gross loss speeds
- Heavier oil increased oil loss speeds

Wave Conformance Tests

- The sweep followed the waves very well
- Boom significant relative motion was 34 to 92 percent of the significant wave height

Oil Loss Rate Tests

- Only limited testing was performed due to time contraints and results are inconclusive

Oil loss speed tests only were performed on the NOFI 600S Oilboom. The 60 meter long oil boom was towed in a U-shaped configuration with a mouth opening of 14 meters, with and without the boom's feather net installed. The lighter test oil was used for all oil boom tests because the temperature was colder for these tests than for the Vee-Sweep tests.

- First loss speeds between 1.0 and 1.3 knots were obtained
- First gross loss speeds of 1.2 to 1.6 knots were measured
- The bottom netting appeared to have little effect in calm water but increased oil loss speeds in waves.

The Vee-Sweep and 600S Oilboom both towed in a very stable manner up to the critical tow speed. The sweep has substantial reserve buoyancy and the apex sank gradually as the tow speed was increased. The shape of the sweep was constant throughout the speed range. The oil loss tests demonstrated that the NOFI Vee-Sweep can contain and concentrate oil at speeds above 1 knots which is a significant improvement over most other boom designs.

1.0 INTRODUCTION

1.1 Purpose of the Test

The NOFI Vee-Sweep is an oil containment sweep with possible application with the U.S. Coast Guard (USCG) Vessel of Opportunity Skimming System (VOSS). The USCG is currently procuring equipment to supplement the inventory of their National Strike Force units. This procurement includes conventional oil-spill containment booms for the VOSS. Currently, the design speed for the VOSS system is 0.75 knots. Many vessels have difficulty maintaining such a slow speed or holding a desired heading at this speed. This problem limits the versatility intended for the VOSS.

The NOFI Vee-Sweep tested is designed to sweep effectively at speeds in excess of 0.75 knots. The OHMSETT tests help to quantify the sweep's operational efficiency at higher speeds. Based on the results of the OHMSETT testing, the USCG may modify the current VOSS contract to obtain equipment that can operate at higher relative velocities.

The NOFI 600S Oilboom was tested to determine its effectiveness with and without the bottom feather netting. These tests were conducted primarily for background information which may prove useful later in the design of booms to meet Coast Guard requirements.

1.2 Background

The NOFI Vee-Sweep has its roots in two Norwegian trawls developed in the late 1970's. Through the Norwegian PFO, Oil Pollution Control Research and Development Program, the best features of the two designs were merged into one trawl that came on the market in 1980. The oil trawl has been in regular use in Norway and in the former USSR.

The Vee-Sweep is an ocean oil boom designed to contain and concentrate oil to be recovered by a skimmer positioned just forward of the apex. The sweep consists of a fabric skirt supported by buoyant cylindrical chambers along the top of the skirt. The sweep is shaped like a V, wider at the mouth than at the apex. It is held in this shape by netting across the bottom of the sweep. The netting is attached on each side to the bottom of the skirt. The bottom netting is made of three sections having differenct mesh sizes. The mesh becomes finer as you move from the mouth of the sweep to the apex. Three tension members are incorporated running along the length of the sweep. Two are located at the top and bottom of the skirt and a third is located at the top of the buoyancy chamber.

The design intent of the NOFI Vee-Sweep is to improve the oil containment capability in the oil recovery portion of the sweep near the apex. In an ordinary catenary shaped oil boom, oil containment has proven very difficult in high seas and when the current or tow speed exceeds 0.7 to 1.0 knots. At these speeds, the oil escapes under the oil boom.

The NOFI 600S Oilboom was designed to attach on one side of the Vee-Sweep. A support boat tows the end of the Oilboom while the skimming vessel tows the other side of the Vee-Sweep. The Oilboom is similar in cross section to the Sweep with a buoyancy chamber above a skirt. A feather net is attached to the bottom of the skirt between the skirt and the bottom tension member. The bottom tension member is a chain which also provides ballast to the skirt bottom.

MAR, Inc., was tasked with developing a test plan for the NOFI sweep, testing the sweep and oilboom, and writing a test report, all under Minerals Management Service OHMSETT Work Order Number WO01AA. The NOFI Vee-Sweep, a NOFI 600S Oilboom, and a DESMI-250 skimmer were provided by the USCG for these tests.

1.3 Objectives

The NOFI Vee-Sweep tests were to determine:

1. Critical tow speed
2. First loss tow speed
3. First gross-loss tow speed
4. Oil loss rate versus tow speed
5. Sweep conformance to wave action
6. Sweep angle as a function of tow speed
7. Oil thickness versus speed at the recommended skimmer position
8. Drag force versus tow speed and time
9. Tension in the sweep tension members

Some of the oil loss tests were repeated with the DESMI-250 skimmer incorporated. The skimmer operated in front of the sweep apex using standard operating parameters. No attempt was made to test the DESMI-250 skimmer. The purpose was to test the NOFI Vee-Sweep under conditions that resembled actual oil skimming operations. No analysis of skimmer performance was made other than that necessary to match the oil recovery rate to the oil distribution rate.

1.4 Scope of the Tests

All testing took place in the OHMSETT test tank at Leonardo, New Jersey. Testing took place between August 13, 1992 and October 6, 1992. The Vee-Sweep was tested to determine the critical tow speed, oil loss speeds, oil loss rate, and wave conformance. The critical tow speed tests determine a limiting towing speed without oil. For the Vee-Sweep, this is the speed at which the apex of the boom submerges. The oil loss speed tests determine the first loss and first gross loss speeds. First loss is the occurrence of droplets of oil escaping under the boom. First gross loss is the occurrence of streams or other gross loan of oil from under the boom. Oil loss rate tests measure how much oil is lost in a given time for various speeds above the first loss speed. Wave conformance tests use pressure sensors on the bottom of the boom skirt to measure the relative motion between the sensors and the water surface. Sensors are placed at a number of positions on the boom to determine how well the boom is conforming to the waves.

The NOFI 600S Oilboom was tested only to determine oil loss speeds. Tests were made with and without the feather netting attached to the bottom of the boom skirt.

2.0 ORGANIZATION

Organizations participating in the testing were:

1. Minerals Management Service
   - Funds the operation of OHMSETT
   - Provided work order tasking to MAR, Inc.
   - Reviewed and approved Test Proposal
   - Reviews and approves Test Reports

2. MAR, inc.
   - Planned, conducted, and reported the tests

3. U.S. Coast Guard R&D Center
   - Provided the NOFI Vee-Sweep, the NOFI 600S Oilboom, and a DESMI-250 Oil Skimmer
   - Provided a Bentech LM200 Subsea Oil Level Meter and sensor technician services.

3.0 TEST SETUP

In its standard configuration, the NOFI Vee-Sweep is too large to accurately test in the OHMSETT facility. The width at the Vee-Sweep mouth is 19.3 meters (64.65 feet), effectively blocking the 20 meter (65.46 foot) width of the test tank. The depth of water in the OHMSETT tank is 2.44 meters (8 feet). The Vee-Sweep comes with a 1000 mm (39.4 inch) deep skirt that can be shortened to 700 mm (27.6 inches) deep. The "Test Protocol for the Evaluation of Oil-Spill Containment Booms" was specified for guidance in conducting the tests. The protocol specifies a minimum wall clearance of 2.5 times the boom's draft. The minimum water depth in the tank is specified as 4 times the boom's draft. Both of these constraints are exceeded for the Vee-Sweep with either the 1000 mm or 700 mm skirt depth if tested as designed. Consequently, the Vee-Sweep was modified slightly to permit its testing at OHMSETT.

The wall clearance was increased by rotating the sides of the Vee-Sweep inward from the apex until the ends of the Vee-Sweep at the mouth were about 1.83 meters (6 feet) in from the tank walls. This provided the 2.5 times draft minimum wall clearance. Each side was swung inward by ~3.5 degrees. The width of the bottom netting was reduced accordingly and secured to the bottom of the skirt to take the lateral forces across the Vee-Sweep. The skirt was shortened to the 700 mm (27.6 inch) skirt depth which giving a water depth to boom draft ratio of 3.5/1.

Even with the above restrictions, the bottom clearance was less than recommended in the protocol. Therefore, the above restrictions were considered the minimum which would provide reasonable test results. All of the tests on the NOFI Vee-Sweep and 600S Oilboom were conducted with this test setup.

Figure 1 shows the test setup and instrument locations.

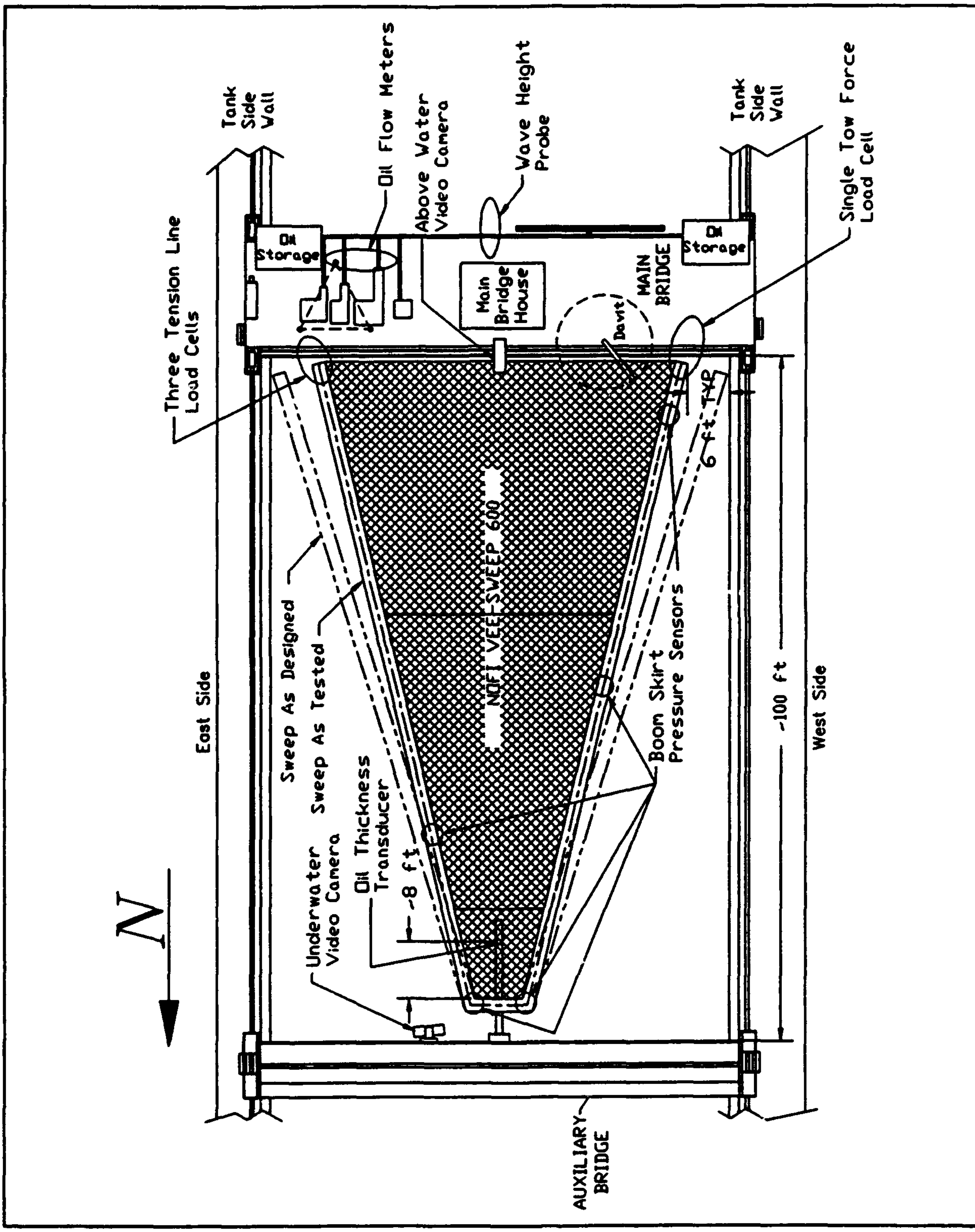

Figure 1. NOFI Vee-Sweep - Plan View.

4.0 NOFI VEE-SWEEP TESTS

4.1 Critical Tow Speed Tests

4.1.1 Objective

The objective of these tests was to determine the critical tow speed for towing the Vee-Sweep without oil. The critical tow speed is the speed at which the sweep either loses all freeboard (submarines), loses all draft (planes), mechanically fails, or the maximum safe tow speed of the test tank is reached. In the case of the Vee-Sweep, the critical tow speed occurred when the apex of the Vee-Sweep submerged. The critical tow speed is a limitation on how fast the sweep can be safely towed from one oil pickup location to another. It does not necessarily represent the maximum speed that the sweep could be towed without damage.

4.1.2 Procedure

The Vee-Sweep was towed in calm water and various wave conditions without oil present. The tow began at approximately 0.5 knots and continued until the Vee-Sweep had formed a catenary. Then the speed was increased by 0.5 knot increments until 2.0 knots was reached. The speed was then increased slowly until the critical tow speed was reached. The critical tow speed was recorded to the nearest 0.1 knot along with the mode of failure.

Four wave conditions were tested in addition to calm water tests for a total of five test conditions. Each of the five test conditions were repeated to confirm the data obtained. In two of the regular wave runs, additional runs were necessary to reach the critical speed or confirm previous data. In total, twelve critical speed runs were conducted.

Three of the wave conditions represented essentially regular waves of a single frequency. Three wave frequencies were chosen to span the test range possible with the OHMSETT wavemaker. The fourth represented a harbor chop condition at a frequency that permitted the maximum amplitude to be generated. To the extent practical, the wave conditions for the critical speed tests were identical to those used in the oil loss tests and wave conformance tests. The nominal significant wave heights and periods for the regular waves, based on previous testing in the tank, were:

Wave height	Period
8.9 inches	4.5 Seconds
4.8 inches	2.5 Seconds
8.1 inches	1.6 Seconds

The nominal significant wave height and period for the harbor chop condition were:

Wave height	Period
18.6 inches	2.0 Seconds

These heights and periods were based on known wavemaker settings. Analysis of wave data showed that the wave heights can vary significantly from these nominal values although the periods are close. Measured values of significant wave height and average apparent period are included in later sections of this report.

4.1.3 Independent Variables

The only independent variables for this test are the wave conditions and the tow speed.

4.1.4 Test Measurements

The following measurements were made for these tests. The critical tow speed was determined by visual observation. The measurements below provide data on the Vee-Sweep performance during high speed tows. Figure 1 shows instrumentation locations. All recorded data was collected at a rate of 10 samples/second.

Time
Tow Speed
Wave Height
Boom Angle at the Sweep Mouth
Tension in Each Tension Line
Tow Force
Air and Water Temperature
Wind Speed and Direction

All twelve critical speed runs were made sequentially, over a two-day period. Environmental conditions were measured for each test run.

Tow force data was recorded from four load cells as shown in Figure 2. On one side of the boom, there were three load cells, one attached to each of the tension lines of the Vee-Sweep. On the other side of the boom, a single load cell was installed to measure the combined load.

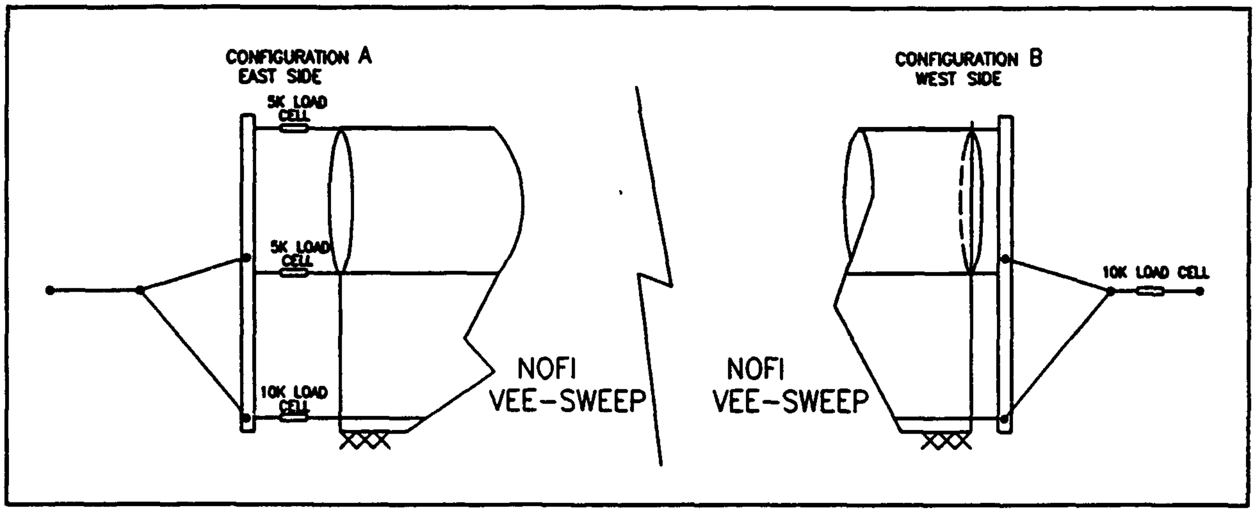

Figure 2. Load Cell Locations.

Wave height versus time measurement were made with the wave probe stationary in the vicinity of the main bridge. Measurements were made before the start and at the end of each run down the test tank. Wave data was collected for 200 seconds at both locations.

Regular waves were generated for four minutes before prerun wave data collection began. Harbor chop conditions were allowed to develop for 15 minutes before beginning data collection.

4.1.5 Instrumentation

Instrumentation for this test is listed in the instrumentation summary in Appendix A.

4.1.6 Analysis of Data

The critical tow speed and mode of failure for each of the twelve test runs is shown in Table 1 along with measured wave characteristics, the test date, and test number. Weather conditions during the runs and wave amplitude spectra for the wave test runs are included in Appendix B. Appendix B includes a discussion about how the wave amplitude spectra were generated.

The significant wave height ($H_{1/3}$) is used in this report to define the height of waves in the wave tests. The significant wave height is defined as the average height of the highest third of the waves within the test record. The average apparent period (A.A.P.) is the average value of the peak-to-peak time intervals. The following paragraphs discuss how the significant wave heights and average apparent periods were computed for these tests.

Table 1. NOFI Vee-Sweep Critical Tow Speed Test Summary.

Date	Test No. #	Wave Condition	$H_{1/3}$* (Inches)	A.A.P.** (Sec)	Critical Tow Speed (Knots)	Failure Mode
8/13	1A	Calm	0	0	3.4	Apex Submerged
8/13	1B	Calm	0	0	3.6	Apex Submerged
8/13	2A	Regular	7.66	4.52	3.2	Wave Over Apex
8/13	2B	Regular	9.26	5.04	3.0	Wave Over Apex
8/13	3A	Regular	10.50	2.54	3.0	Wave Over Apex
8/14	3B	Regular	7.61	2.45	2.6	Wave Over Apex
8/14	3B1	Regular	8.30	2.51	2.8	Wave Over Apex
8/14	4A	Regular	4.82	1.69	2.4	Wave Over Apex
8/14	4B	Regular	4.13	1.62	2.6	Wave Over Apex
8/14	4B1	Regular	4.40	1.85	3.5	Apex Submerged
8/14	5A	Harbor Chop	13.72	2.30	2.4	Apex Submerged
8/14	5B	Harbor Chop	14.97	2.32	2.4	Apex Submerged

- Full Test Numbers Include a W01T Prefix, e.g., W01T1A
* - Significant Wave Height
** - Average Apparent Period of Waves

The wave data (from the acoustic wave probe) were first modified by a computer program which filtered out noise spikes (a characteristic of the acoustic probe). The filtering was done point-by-point in two stages. In the first stage, the user entered the approximate mean value (still water level) and an amplitude value slightly higher than the maximum possible wave amplitude. Any wave probe values which fall outside the range of the mean value plus or minus the maximum amplitude value were eliminated and replaced by the value of the previous data point. The

mean and standard deviation of the water surface were then calculated for the data without these spikes. In the second stage of filtering, any values which exceed *m* standard deviations greater than or less than the mean value were removed and replaced by the value of the previous point. For the data in the NOFI tests, a value of $m = 2.5$ was used. It was found that once the spikes were removed in the first stage of filtering, the second stage of filtering did not alter the data for the NOFI tests.

The modified date file were then analyzed to identify peaks and subsequent troughs. The data sets were read sequentially. A peak is defined as a value which both exceeds the mean water level and is greater than the *n* values which precede and follow it. The value of *n* can be selected by the user to suit the noise in the data; $n = 3$ (with the data points 0.1 sec apart) was used in analyzing the data from these tests. This value was found by trial to work best for identifying the true peaks and troughs. Once a peak was identified, the following trough was found by looking for a point below the mean water level and less than the *n* values which precede and follow it. When a trough was found, the search began for the next peak, and so on through the data.

The peak-to-trough height differences and the peak-to-peak time intervals were saved in arrays. Once all peaks and troughs in the data had been identified, the values in the peak-to-peak time interval array were averaged to give the average apparent period. The height difference array was sorted by magnitude, and the highest third of the values were averaged to determine the significant wave height.

Environmental variables - air temperature, water temperature, wind speed, and wind direction for the critical speed tests are shown in Table B-1 Appendix B.

The critical speed runs were used to determine tow force versus speed. These runs cover the largest speed range of all the tests and are the only ones which measure tow force at the highest speeds. It was planned to increase speed in steps from the lowest to the highest speed. However, the tow carriage controls do not permit such fine adjustment. As a result, the carriage speed was increased slowly and as smoothly as possible up to the maximum speed. This introduced acceleration forces. Detailed analysis showed that the measured tow forces were little affected by the levels of acceleration used. Therefore, the data was not corrected for the effect of acceleration. Smoothing was performed on the data using a running average of 11 data points, about 1 second, throughout the speed range.

Tow force versus speed plots for the calm water case are shown in Figure 3. Tow forces for the runs in waves are shown in Figures B-1 to B-4 in Appendix B. In each figure, the bottom plots show the data from the bottom, top and middle load cells for each run repetition. The top plot shows the data from the single load cell and the sum of the data from the three load cells on the other end of the sweep. Since the sweep is symmetrical, the tow force on one side should be equal to the force on the other side.

The tow force data shown on the plots is the tow line force on one side of the Vee-Sweep in line with the sweep side. The total tow force required to tow the Vee-Sweep at various speeds can be computed by multiplying the tow force from the plots by twice the cosine of the tow angle. The tow angle is the angle between the forward end of the Vee-Sweep and the longitudinal axis of the tank. During the test runs, the tow angle was measured from video tape views of the Vee-Sweep taken from the tower on the main bridge. The tow angle at all speeds and test conditions was between 14 and 15 degrees. This compares to a static angle of 12 degrees based on a 16.33 meter (53.46 foot) mouth opening, a Vee-Sweep longitudinal length of 28.31 meters (92.89 feet), and an apex width of 3.36 feet (11.0 feet). The constant sweep tow angle with speed was expected because the bottom netting limits the Vee-Sweep's lateral travel. The top of the forward end of the Vee-Sweep did rotate outward relative to the bottom of the skirt which accounts for the difference between the static angle and the tow angle underway. This rotation reaches a maximum at low speed and remains constant for higher speeds. The apex of the Vee-Sweep is fixed at both the bottom of the skirt, by the netting, and at the top, by the floatation and does not change position with speed. The Vee-Sweep sides maintained nearly a straight line from the forward end to the apex as shown in Figure 1.

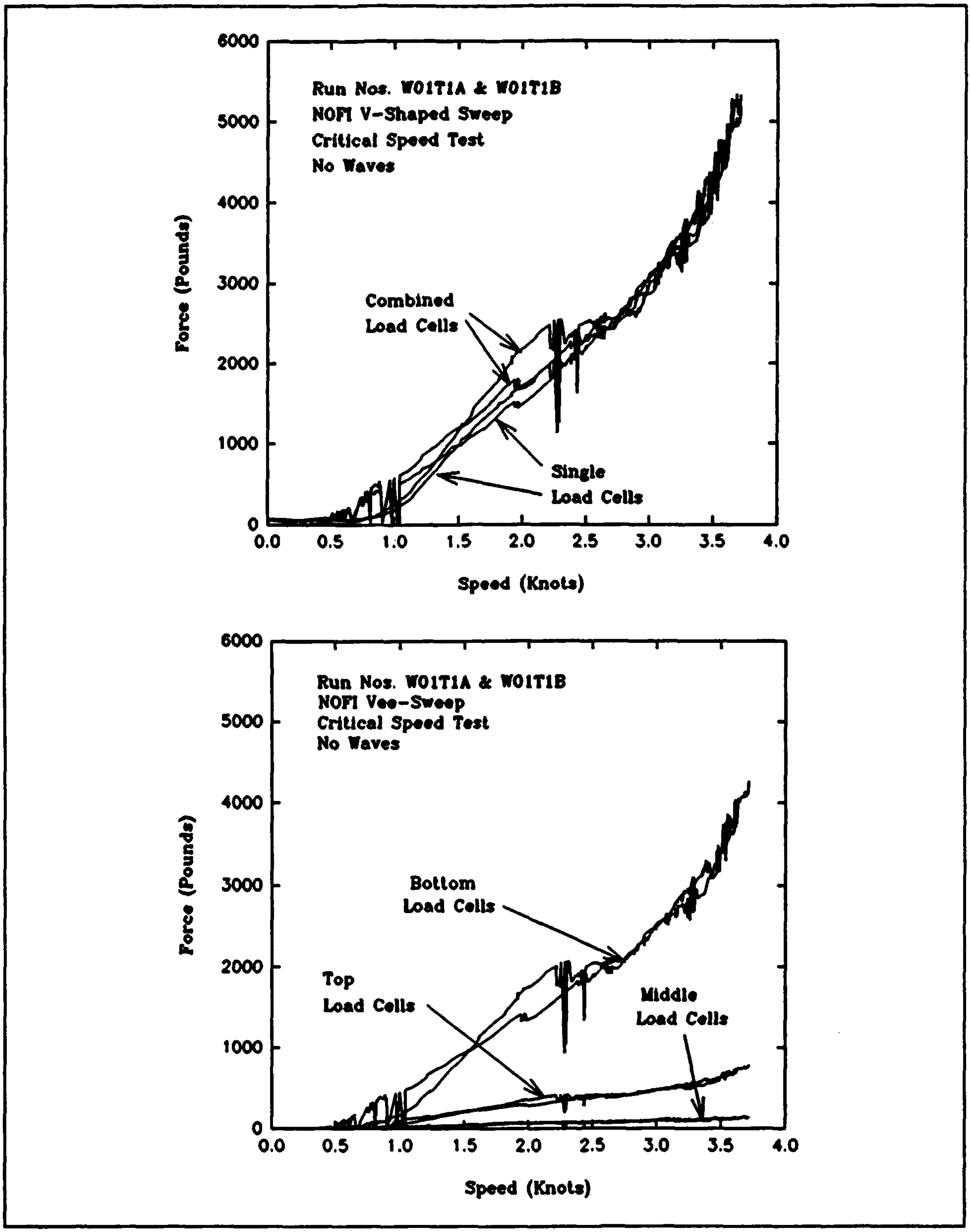

Figure 3. Tow Force versus Speed - Calm Water.

4.1.7 Data Quality

Instrumentation calibration is discussed in Appendix D. The principal results of these tests were visual observations of the critical tow speeds. Table 1 shows the repeatability of this observation between two tests under the same conditions. Test 3B was repeated because the NOFI TROMSØ representative, Karre Davidson, noted that the sweep air bladders were underinflated. The speed did increase in the repeat run, 3B1, after the bladder inflation was increased. Several of the runs were terminated when large waves washed over the Vee-Sweep apex. Further observations indicated that the Vee-Sweep would recover and resurface after a brief submergence. Later tests were continued until the Vee-Sweep apex submerged and remained submerged. Test 4B1 was a repeat of test 4B continued to a higher speed. The critical tow speed for the Vee-Sweep changed very little due to the small amplitude waves used for testing. The critical tow speed was 3.4 to 3.6 knots in all calm water and regular wave tests that continued until the apex submerged. Observations of boom performance showed that the boom was following the small waves closely. Given these observations and the data collected, we believe that the critical tow speed for full submergence is 3.4 to 3.6 knots for calm water and each of the regular waves tested. However, in the higher amplitude harbor chop waves the boom only reached a 2.4 knot critical speed which indicates that the critical speed will be lower in larger waves, as expected.

The data plots of tow force demonstrate the accuracy and repeatability of the tow force data between runs and between load cells. The difference between the sum of the three load cells on one side of the Vee-Sweep and the combined load cell value from the other side of the Vee-Sweep is within 10 percent of full scale over the speed range. The difference is 2 to 3 percent over much of the speed range. The difference in tow force between test runs ranged from 6 to 25 percent of full scale. Some inaccuracy is present in the tow force values due to acceleration.

Appendix B includes a discussion of the accuracy of wave spectra. Appendix B also includes a table showing the difference between the waves before the test run and after the test run. In general, the waves were quite stable during each test in spite of apparent visual differences in amplitude observed in the tank. The wave energy spectrum is not changing significantly with time.

4.2 Oil Loss Speed Tests

4.2.1 Objective

The main objectives of these tests were to determine the first loss tow speed and the first gross loss tow speed under various wave conditions. The first loss tow speed is the speed at which droplets of oil first begin to escape under the sweep. The first gross loss tow speed is the speed at which large amounts of oil begin to be lost from under the sweep. With lighter oils, the first gross loss speed usually results in streams of oil appearing from under the sweep. With the high viscosity oil used in the NOFI tests, the oil remained in droplets but the number of droplets increased very rapidly once first gross loss speed was reached. Determination of the both oil loss speeds is subjective based on observations using an underwater camera. The first loss speed is easy to determine. The first gross loss speed is also much easier to determine than might be expected because the increase in oil loss rate at first gross loss speed is very dramatic. Between first loss and first gross loss speeds, the increase in oil loss rate is gradual.

The majority of the oil loss tests were conducted with the Vee-Sweep alone but a few were made with a DESMI-250 oil skimmer present and operating. The tests with the skimmer present were performed to see if the oil loss speeds varied from the speeds determined without a skimmer

Another objective, determining oil thickness at the location of the skimmer versus tow speed, was covered partly by this test and partly by the oil loss rate tests described later.

4.2.2 Procedure

These tests were conducted in two phases. In Phase 1, only the Vee-Sweep was towed. In Phase 2, a DESMI-250 oil skimmer was positioned in the Vee-Sweep. The center of the skimmer was approximately 1.8 to 2.4 meters (6 to 8 feet) forward of the Vee-Sweep apex. The skimmer was operated during the tests as described under Phase 2 below. The skimmer's self adjusting weir lip (light oil adapter) was used in these tests.

During the oil loss tests it became obvious that the 0.38 M^3 (100 gallon) preload was not sufficient to have oil at the skimmer position. Also, the small preload did not cover the oil thickness sensor. As a result, some additional tests were added using a 3.41 M^3 (900 gallon) preload. This 3.41 M^3 preload was used for all Phase 2 tests with the skimmer and for some Phase 1 tests.

<u>Phase 1 Procedures</u>

The Vee-Sweep was towed in calm water and various wave conditions with a preload of 0.38 M^3 (100 gallons) and, in some cases, 3.41 M^3 (900 gallons) of oil. The bridge was moved to allow the oil preload to enter the Vee-Sweep. It was then moved towards the apex using fire hoses while the Vee-Sweep was returned slowly to the north end of the OHMSETT tank. After reaching the end of the tank and after prerun wave data was taken, the Vee-Sweep was accelerated to about 0.8 knots. The speed was then increased by approximately 0.1 knot increments until the first loss tow speed was reached. The first loss tow speed was recorded to the nearest 0.1 knot based on underwater video observations on all days except August 18th. The underwater video camera was not operational on that day and above water observations had to be used to determine speeds.

After the first loss tow speed was reached, the increase in tow speed was continued until the first gross loss tow speed was reached. The first gross loss tow speed was recorded to the nearest 0.1 knots based on the same observation techniques used to determine first loss tow speed.

For the 0.38 M^3 (100 gallon) preload case, four wave conditions were tested in addition to calm water tests for a total of five test conditions. The wave conditions used were kept as identical as possible to those used in the critical speed tests. Each of the five test conditions were repeated to confirm the data obtained, for a total of ten test runs.

Additional tests for calm water and the 1.6 second period regular wave were made with a 3.41 M^3 (900 gallon) preload instead of 0.38 M^3 . These tests were also duplicated. A final pair of tests were conducted with Hydrocal 300®, in lower viscosity oil, in calm water conditions. Sixteen oil loss tests in all were conducted. The two preloads used permit the effect of preload amount on loss speed to be determined. Tests with the two different viscosity oils were conducted to see if oil viscosity affected oil loss speed and to allow comparison of sweep performance to past Ohmsett tests which were conducted with lower viscosity oils similar to Hydrocal 300®.

Phase 2 Procedures

The Vee-Sweep and DESMI-250 skimmer were towed in calm water and one wave condition with a preload of 3.41 M^3 (900 gallons) of oil. Because of the large amount of oil in the preload, a fresh preload of oil was not used for each test run. The tow began at about 0.5 knots below the first loss tow speed determined without the skimmer and continued until the oil preload had been distributed and had stabilized at the apex of the Vee-Sweep. Once the preload stabilized, oil was distributed across the sweep's mouth at a rate which varied from 0.55 to 1.02 M^3/Min (146 to 270 GPM). The DESMI-250 skimmer was started once this oil reached the preload. The skimmer was regulated to pump out oil at approximately 0.95 M^3/Min (250 GPM) by Flemming Hvidbak of DESMI, Inc., using known skimmer control settings.

With the skimmer regulated, the tow speed was increased in 0.1 knot increments until the first loss tow speed was reached. The first loss tow speed was recorded to the nearest 0.1 knot based on above water and underwater video observations as in Pase 1 tests.

The tow speed was further increased by 0.1 knot increments until the first gross loss tow speed was reached. The first gross loss tow speed was recorded to the nearest 0.1 knots also based on above water and underwater video observations. Oil distribution stopped when the first gross loss tow speed was reached.

One wave condition was tested in addition to calm water tests for a total of two test conditions. The 1.6 second period wave used in Phase 1 was used for tests with the skimmer. Each of the two test conditions was repeated to confirm the data obtained, for a total of four test runs. One run in calm water, 11B, was invalid because the operator didn't receive word in time to start the skimmer. This test was rerun as 11C.

Oil Used in Both Phases

The test oil used for all tests except two Phase 1 tests was SUNDEX 8600T from SUN Refining and Marketing Company which has the following advertised characteristics:

Viscosity	1763 cSt @ 40°C
Specific Gravity	0.962

The oil used for the remaining two tests was a medium viscosity oil having the tradename Hydrocal 300® produced by Calumet Lubricants Co. Hydrocal 300 has the following advertised characteristic:

Viscosity	140 cSt @ 25°C
Specific Gravity	0.899

Measured oil characteristics are given in Appendix C. Estimated viscosities are shown in Tables 3 and 4 based on an estimated oil temperature using the procedure described in section 4.2.6, Analysis of Data.

4.2.3 Independent Variables

The only planned independent variables for these tests were the wave conditions and the tow speed. Oil distribution rate and oil recovery rate in Phase 2 probably affect the results of those tests. An effort was made to keep the

distribution rate at 0.47 M^3/Min (125 GPM). However, the OHMSETT oil distribution system did not allow the fine control needed to do this. The current procedure is to recirculate the oil through a flow meter while adjusting the flow rate. When the meter reads the correct rate, the discharge valve is opened to distribute the oil. However, the pressure drop in the discharge line is less than in the recirculation line. As a result, the flow rate increases by up to double. There is a flow totalizer on the discharge line which allows the actual rate to be determined after the fact. The actual distribution rate varied between 0.55 and 1.02 M^3/Min (146 and 270 GPM).

4.2.4 Test Measurements

The first loss and first gross loss tow speeds were determined by visual observation using primarily the underwater video camera to observe oil flow. The underwater video camera was not operational on August 18th. Observations of the two oil loss speeds were instead made by a person standing on the auxiliary bridge on August 18th. With both the observer and underwater video approach, there was a short time delay (1 to 2 seconds) between sighting the oil loss and reading carriage speed. This did not affect the speed measurements greatly as the acceleration averaged about 0.02 knots/sec. An electronic marking device was added as a result of these tests to allow a mark to be placed on the recorded time channel to identify key events. The operator now needs only to push a button when an event is noted, the value of speed or other recorded data at the time mark can be determined later. Figure 1 shows instrumentation locations. The following measurements were made for this test. Recorded data was collected at 10 samples/second.

- Time
- Tow Speed
- Wave Height
- Oil Thickness at Skimmer Location
  (Phase 1, 900 gallon preload only)
- Boom Angle at the Sweep Mouth
- Tension in Each Tension Line
- Tow Force
- Air and Water Temperature
- Wind Speed and Direction

Most Phase 1 testing took place on August 18, 19, and 20, 1992. Additional tests were conducted on August 27th, September 15th and September 16th. Phase 2 tests were conducted on August 24th and 25th. Environmental data was collected for each of the test runs. Wave height versus time measurements were made with the wave probe stationary in the vicinity of the tow carriage. Measurements were made before the start and at the end of each run down the test tank. Wave data was collected for 200 seconds both before and after the run.

Regular waves were generated for four minutes before prerun wave data collection began. Harbor chop conditions were allowed to develop for 15 minutes before beginning data collection.

Oil samples were collected and analyzed. The results of this analysis are in Appendix C.

The oil thickness was determined by observing the forward extent of the oil in the Vee-Sweep. The average thickness could then be calculated knowing the area of oil in the Vee-Sweep and the amount of oil distributed. Readings were available from the oil thickness meter in very few cases as the meter was generally forward of the oil in the Vee-Sweep. By mutual agreement of the sponsors, the meter was not relocated nearer the apex due to the delays in testing that such a move would have entailed.

In phase 2, the skimmer recovery rate was determined by measuring the quantity of fluid recovered over a timed interval (1 to 5 minutes). The percentage of oil was found after the recovered fluid had settled in the recovery tank and the bottom water had been drained off. The quantity of remaining fuid was calculated and a stratified thief sample was taken of this fluid. The remaining water and bottom solids were determined by testing the fluid sample

in the laboratory. The total amount of oil recovered could then be found by deducting the percent of water and bottom solids from the quantity of fluid remaining in the tank. The amount of oil was divided by the total amount of fluid recovered to determine the recovery efficiency (RE).

4.2.5 Instrumentation

The instrumentation for this test is common with the other Vee-Sweep tests and is listed in Appendix A.

4.2.6 Analysis of Data

Phase 1

The first loss and first gross loss tow speeds for the Phase 1 test runs are shown in Table 3. Environmental data associated with the Phase 1 tests are included in Table B-2 of Appendix B.

Wave data is shown in the form of wave amplitude spectra in Appendix B. The wave data collected before and after each run were combined to determine the apparent period and significant wave height which are shown in Table 3. The critical speed tests discussion explains how these values were computed. The data collection system failed to save data on several of the tests for reasons not yet determined. The tests were not repeated as the primary data, first loss speed and first gross loss speed, were obtained through visual observation. Nominal wave characteristics have been shown for the cases where data is not available.

Tow forces were collected as a backup to tow force measurements during the critical speed runs but were not analyzed. The critical speed tests encompass the same speeds used for the oil loss tests. Refer to the critical speed test discussion for data on tow forces. The towing angle of the sweep at its mouth is also discussed under the critical speed test section.

It was planned to use a Bentech Subsea LM200 oil thickness sensor to determine the oil thickness at the skimmer location during these tests. The LM200 was checked and calibrated using a measured depth of oil in the OHMSETT 18.93 M^3 (5,000 gallon) vertical tank. An operating depth of 760 mm (30 inches) was used for calibration. During testing, the sensor was mounted below the Vee-Sweep's bottom netting on an arm supported by the auxiliary bridge. The sensor was positioned about 2.4 meters (8 feet) forward of the sweep's apex and 1.52 meters (60 inches) below the water surface. During some of the return runs the Vee-Sweep's net got tangled with the sensor and changed the aim point. The sensor was not functional from the point on. Time did not permit repositioning the sensor and readjusting the signal.

Table 2. Oil Thickness (NOFI Vee-Sweep)

Test No.	Condition	Speed (Knots)	Oil Thickness (Inches)
9C	At Start	0.2	1.7
	1st Loss	1.0	9.5
	Gross Loss	1.3	10.7
9C1	At Start	0.2	1.7
	1st Loss	1.0	9.5
	Gross Loss	1.4	11.9

There was no oil over the Bentech sensor during the 0.38 M^3 (100 gallon) preload tests. All of the oil was in the last 1.2 M (4 feet) of the Vee-Sweep. Also, the oil covered such a small surface area and had such an irregular leading edge that it was not possible to accurately calculate the oil thickness for the 0.38 M^3 preload tests.

The thickness of oil for two of the 3.41 M^3 (900 gallon) preload runs was calculated using the distance from the apex to the forward edge of the oil, the known shape of the boom, and the quantity of oil in the preload. Tape marks were place on the boom and the forward extent of the oil was noted visually. Oil thickness was computed for various speeds using runs 9C and 9C1 as shown in Table 2.

Table 3. Oil Loss Speed Test Phase 1 Summary (NOFI Vee-Sweep).

Date	Test No.	Wave Condition	$H_{1/3}$* (Inches)	A.A.P.** (Secs)	1st Loss Speed (Knots)	1st Gross Loss Speed (Knots)	Oil Preload/ Est. Oil Viscosity ***
8/18	6A	Calm	0	0	1.4	1.8	100 Gal/16500 cSt
8/18	6B	Calm	0	0	1.4	1.8	100 Gal/9300 cSt
8/18	7A	Regular	(8.9)	(4.6)	1.4	1.6	100 Gal/9900 cSt
8/18	7B	Regular	(8.9)	(4.6)	1.3-1.4	1.6-1.7	100 Gal/9900 cSt
8/20	8A	Regular	6.04	2.56	1.5	1.7	100 Gal/9900 cSt
8/20	8B	Regular	(4.8)	(2.5)	1.5	1.7	100 Gal/9900 cSt
8/20	9A	Regular	4.57	1.59	1.3	1.7	100 Gal/9800 cSt
8/20	9B	Regular	4.20	1.61	1.3	1.6	100 Gal/9700 cSt
8/20	9C	Regular	(8.1)	(1.6)	1.0	1.3	900 Gal/9700 cSt
8/20	9C1	Regular	(8.1)	(1.6)	1.0	1.4	900 Gal/13700 cSt
8/27	9D	Calm	0	0	1.2	1.6	900 Gal/7500 cSt
8/27	9D1	Calm	0	0	1.3	1.6	900 Gal/8300 cSt
9/15	10A	Harbor Chop	(18.6)	(2.0)	> 1.3#	#	100 Gal/19800 cSt
9/15	10B	Harbor Chop	(18.6)	(2.0)	> 1.8#	#	100 Gal/19800 cSt
9/16	25A	Calm	0	0	1.0-1.1	1.4	100 Gal/370 cst
9/16	25B	Calm	0	0	1.1	1.3-1.4	100 Gal/370 cst

* - Significant Wave Height, nominal values are shown in ()s for tests where the data collection system failed. Actual amplitudes vary significantly from nominal values in other runs. Nominal values should be used with caution.

** - Average Apparent Period of Waves, nominal data shown in ()s.

*** - See text for a discussion of temperatures used in computing oil viscosity.

\# - Data collection system failed. Only limited manual data is available.

Test 12A was an oil loss test run with the skimmer present. The intention was to skim at the same rate as oil was being distributed. The test started with a precharge of 3.41 M^3 (900 gallons). After start-up, the area covered by the oil remained nearly constant. The oil thickness for this test was calculated to be 180 to 230 mm (7 to 9 inches) at the first loss speed. The distribution rate during this test was 0.8 M^3/Min (211 GPM) and the recovery rate was 0.61 M^3/Min (162 GPM).

Phase 2

The first loss and first gross loss tow speeds for the Phase 2 test runs is shown in Table 4. Table 4 gives the computed recovery efficiency, oil recovery rates and distribution rates for the tests with the skimmer in the Vee-Sweep. Environmental data associated with the Phase 2 tests is included in Table B-3 of Appendix B. Wave data is shown in the form of wave amplitude spectra in Appendix B. The wave probe data before and after each test run was combined in order to determine the average apparent period and significant wave height for each test run which are shown in Table 4.

Table 4. Oil Loss Speed Test Phase 2 Summary (NOFI Vee-Sweep).

Date	Test No.	$H_{1/3}$* (Inches)	A.A.P.** (Secs)	Oil *** Visc. (cSt)	1st Loss Speed (Knots)	1st Gross Loss Speed (Knots)	Oil Dist. Rate (GPM)	RE# (%)	Skimmer Recovery Rate (GPM)
8/24	11A	0	0	10400	1.3	1.5	270	73.6	175
8/25	11B	0	0	---	1.1	1.4	---	---	Invalid Test
8/25	11C	0	0	4700	1.1	1.6	146	59.3	129
8/25	12A	4.27	1.48	3600	1.2	1.3	211	83	162
8/25	12B	4.21	1.57	5900	1.2	1.4	173	80	186

Sweep preload was 900 gallons for all tests except 11C. For 11C, the oil discharged in 11B was added to the preload for a total of 1900 gallons.
* - Significant Wave Height.
** - Average Apparent Period of waves.
*** - See text for a discussion of the temperatures used when computing oil viscosity.
# - Recovery Efficiency, i.e., percent of oil in recovered fluid.

Both Phases

It was assumed going into these tests that the oil would rapidly reach the temperature of the water in the tank after being distributed on the water. For this reason, it was intended to compute the oil viscosity using the tank water temperature. The high viscosity test oil used for these tests had to be heated to pump it. The oil was maintained at a temperature of 32.2°C (90°F) in thermostatically controlled heated tanks on the main bridge. However, for test 11C, 12A, and 12B, the oil had recently been transferred from the main storage tanks and was at a temperature of 40°C (104°F) prior to the tests. Water temperature for the Phase 1 tests averaged 23.6°C (74.5°F). For the Phase 2 tests, the water temperature averaged 25.3°C (77.5°F). Recovered oil temperature measurements were made during the Phase 2 tests which showed that the oil was not reaching the water temperature very quickly. In fact,

it took approximately one half hour for the oil temperature to fall to the mid temperature between the temperature of the oil in the storage tank and the water temperature. The oil viscosities shown in Tables 3 and 4 have been estimated from the known water temperature and storage tank temperature and the estimated time between when the oil was distributed and when the test was conducted. For estimation purposes it has been assumed that the oil temperature drops linearly from the storage tank temperature to the water temperature over a one hour period. The actual temperature curve approaches the water temperature asymptotically over a longer period of time.

4.2.7 Data Quality

Instrumentation calibration is discussed in Appendix D. The principal results of these tests were visual observations of the first loss and first gross loss speeds. Tables 3 and 4 show the repeatability of these observations between two tests under the same conditions. Data was obtained for all test conditions except for harbor chop. During the harbor chop tests, the data system failed to record carriage speed and these speeds were not recorded manually as in other tests. However, it was noted in test 10A that a speed of 1.3 knots was attained without loss of oil. In test 10B, a speed of 1.8 knots was attained with no oil loss. The oil was more viscous than in some of the other tests which may account for the higher speeds without loss. Underwater video is available for these tests but it can not be correlated with carriage speed. Time did not permit rerunning the tests.

The Phase 2 tests show repeatability to the precision of measurement in spite of the fact that the oil distribution rate varied from 0.556 to 1.02 M /Min (146 to 270 GPM). Measurement precision for speed was ± 0.1 knots. Within this precision of measurement, the first and gross loss speeds are the same as those obtained without the skimmer with the exception of first loss speed in waves. In waves, the skimmer did increase the first loss speed by 0.2 knots but the gross loss speed remained the same as without the skimmer. However, these conclusions should be used with caution as the desired test conditions were not met for any of the tests. That is, the oil distribution rate and the skimmer recovery rate were not equal and different distribution rates were used for each test.

Recovery efficiency is shown in Table 4 but this test was designed to test the Vee-Sweep only and not the DESMI-250 skimmer. Therefore, the skimmer recovery efficiency may not be representative of actual service conditions.

The critical speed test discussion includes details of how the average apparent period and significant wave height were computed. Appendix B includes a discussion of the precision and accuracy of wave spectra. Appendix B also includes a table showing the difference between the waves before the test run and after the test run.

4.3 Wave Conformance Tests

4.3.1 Objective

The objective of these tests was to determine motions of the Vee-Sweep to allow correlation with oil loss.

4.3.2 Procedure

The Vee-Sweep was towed in various wave conditions without oil present. The tests were conducted at the first loss tow speed (without a skimmer) determined during the oil loss test for each condition tested. Each test run was made over the maximum possible length of the tank. Changes in local sweep depth were measured by pressure sensors mounted to the bottom of the sweep skirt. The vertical motion at the sweep apex is the most critical. Therefore, two pressure sensors were located at the sweep apex. Unfortunately, the sensor at the right side (looking forward) of the apex failed before the conformance tests began and was not usable. Another sensor was located 1/4 of the distance from the apex to the sweep mouth on the left side of the sweep. A fourth sensor was located 1/2 of the distance from the apex to the sweep mouth on the right side of the sweep as shown in Figure 1. A fifth sensor was added near the mouth of the sweep on the right side. This fifth sensor also failed early in the test series and was not used during the wave conformance tests.

Four wave conditions were tested. The test conditions were not repeated except in the case of the harbor chop. For the harbor chop tests, the first loss speed was not available from the oil loss tests because the data collection system failed. The harbor chop wave conformance tests were run at two speeds to span the estimated first loss speed. Speeds of 1.0 and 1.2 knots were used. The same waves were used as were used in the critical speed and oil loss tests.

4.3.3 Independent Variables

The only independent variable for this test was the wave conditions.

4.3.4 Test Measurements

The following measurements were made for this test. Figure 1 shows instrumentation locations.

Time
Distance Between Bottom of Sweep Skirt and Water Surface
Tow Speed
Wave Height
Air and Water Temperature
Wind Speed and Direction

All test runs were made on September 14 and 15, 1992.

Wave height versus time measurements were made with the wave probe stationary in the vicinity of the tow carriage. Measurements were made before the start and at the end of each run down the test tank. Data was collected for 200 seconds at a rate of 10 samples/second both before and after the run.

Regular waves were generated for four minutes before prerun wave data collection began. Harbor chop conditions were allowed to develop for 15 minutes before beginning data collection.

4.3.5 Instrumentation

The instrumentation for this test is common with the other sweep tests and is listed in Appendix A.

4.3.6 Analysis of Data

Wave data at the start and end of each of the runs are included in the form of combined (average) wave amplitude spectra in Appendix B. The apparent period and significant wave height are shown in Table 5. The critical speed tests discussion explains how these values were computed.

Vee-Sweep skirt pressure measurements are presented in the form of relative amplitude spectra in Appendix B. Only amplitude differences are shown. Thus, if the bottom of the skirt was following the wave exactly, there would be no relative amplitude. These spectra are scaled to represent the relative motion amplitude between the bottom of the skirt and the water surface and are corrected for the speed of advance. The average apparent period (A.A.P.) and significant relative skirt motion height ($H_{1/3}$) at each sensor are shown in Table 5. The average apparent period has been adjusted for the speed of advance.

Environmental variables - air temperature, water temperature, wind speed, and wind direction - are shown in Table B-4 in Appendix B.

4.3.7 Data Quality

Instrumentation calibration is discussed in Appendix D. Appendix B includes a discussion of the accuracy of wave spectra. This same discussion applies to the spectra generated from the pressure sensors. Only one run was made at each wave condition so no comparison between runs can be made. All data on boom significant relative motion lies between 34 to 92 percent of the significant wave height which is a reasonable range for this data. Also, the two harbor chop conditions have identical significant height ratios even though they were conducted at different speeds and wave heights. This may be only incidental given the differences in the other variables.

Table 5. Wave Conformance Test Summary (NOFI Vee-Sweep).

Date	Test No.	Tow Speed (Knots)	Press. Sensor Location	Relative Motion		Waves		
				$H_{1/3}$* (Inches)	A.A.P.** (Secs)	Type	$H_{1/3}$* (Inches)	A.A.P.** (Secs)
9/15	14A	1.4	Left Apex	3.36	3.56	Regular	8.47	3.68
			Left 3/4 Point	3.91	4.36			
			Right Midpoint	2.90	3.72			
9/15	15A	1.5	Left Apex	5.60	2.77	Regular	6.79	2.49
			Left 3/4 Point	4.17	2.64			
			Right Midpoint	6.28	2.52			
9/14	16A	1.3	Left Apex	2.46	1.69	Regular	4.66	1.59
			Left 3/4 Point	2.91	1.83			
			Right Midpoint	2.90	1.84			
9/15	17A	1.2	Left Apex	13.05	2.25	Harbor Chop	19.96	2.32
			Left 3/4 Point	10.92	2.59			
			Right Midpoint	10.80	2.66			
9/15	17B	1.0	Left Apex	9.07	2.58	Harbor Chop	13.83	2.36
			Left 3/4 Point	7.43	2.40			
			Right Midpoint	8.77	2.49			

* - Significant Wave Height
** - Average Apparent Period of waves

4.4 Oil Loss Rate Tests

4.4.1 Objective

The primary objective of these tests was to quantify the steady state oil loss rate in calm water. Measuring the steady state oil loss requires maintaining the quantity of oil in the preload as the oil is being lost.

A second objective, determining oil thickness at the location of the skimmer versus tow speed, was covered partly by these tests and partly by the oil loss tests described previously.

4.4.2 Procedure

The Vee-Sweep was to be towed in calm water at four speeds that span the interval from the first loss speed up to 0.4 knots above the first loss speed. Speeds above the first loss speed of 0.1, 0.2, 0.3, and 0.4 knots were to be tested. The time available for these tests did not permit completion of all these test conditions. Three conditions were tested. In the first test, 21A, the Vee-Sweep was preloaded with 0.38 M^3 (100 gallons) of oil. The oil distribution system was activated and the Vee-Sweep gradually accelerated allowing the oil front to reach the apex. Once this occurred, the Vee-Sweep was accelerated to the first loss speed plus 0.48 knots. The run continued for as long as the test tank length permitted. The elapsed time was recorded for use in calculating the oil loss rate.

The preload volume of oil was increased to 1.51 M^3 (400 gallons) for test 19A and the test was run at first loss speed plus 0.27 knots. Test 23A used a 3.41 M^3 (900 gallons) preload but with no oil distributed during the run. The tow speed was approximately 0.42 knots above first loss speed. The remaining test runs in this series were not performed due to time constraints on removing and shipping the NOFI Vee-Sweep and beginning the NOFI 600S Oilboom tests.

All oil lost behind the Vee-Sweep was skimmed from the water surface and collected in a calibrated settling tank. The oil loss rate of the Vee-Sweep was computed from the amount of oil recovered in the settling tank.

The test oil for these tests was a high viscosity oil manufactured by SUN Refining and Marketing Compnay under the trade name SUNDEX 8600T®. SUNDEX 8600T has the following characteristics. Estimated oil viscosity at the time of each test in included in Table 6.

Viscosity	1763 cSt @ 40°C
Specific Gravity	0.962

4.4.3 Independent Variables

The only independent variable planned for this test was tow speed. As the test was actually conducted, the oil preload and oil discharge rate were also varied for each of the three test runs in an effort to determine the best test procedure. The runs were made in the last few days of testing for the Vee-Sweep. Time did not permit collecting additional data necessary to determine how each of the independent variables affected the results.

4.4.4 Test Measurements

The following measurements were made for this test. Figure 1 of this report shows instrumentation locations.

Time
Tow Speed
Oil Distribution Rate
Oil Thickness at Skimmer Location
Air and Water Temperature

Wind Speed and Direction

Environmental conditions were measured for each run and these measurements are tabulated in Appendix B. The test oil was sampled and results are presented in Appendix C.

Once the water in the recovered oil settled out in the settling tank, as much free water as practical was drained from the oil and oil/water emulsion. The remaining fluid in the settling tank was sampled using a stratified sample thief. The quantity of water in the remaining fluid was determined from the total stratified sample. From this the quantity of oil lost and the oil loss rate were computed for each test.

The oil thickness was measured by observations of the amount of area the oil covered. Since the quantity of oil in the Vee-Sweep was changing, this method could only give an approximate thickness. A discussion of the thickness measurements is included in Section 4.2.

4.4.5 Instrumentation

The instrumentation for this test is common with the other Vee-Sweep tests and is listed in Appendix A.

4.4.6 Analysis of Data

Data from the three test runs is summarized in Table 6. Environmental variables - air temperature, water temperature, wind speed, and wind direction - are shown in Table B-5 in Appendix B. Section 4.2.6 discusses how the oil temperature was estimated. The viscosity shown in Table 6 is based on this estimated oil temperature and the viscosity/temperature characteristics for each oil type reported in Appendix C.

Table 6. Oil Loss Rate Test Summary (NOFI Vee-Sweep).

Date	Test No.	Tow Speed (Knots)	Oil Preload (Gals)	Est. Viscosity (cSt)	Oil Discharge Rate (GPM)	Volume of Recovered Oil (Gals)	Recovery Time (Min)	Oil Loss Rate (GPM)
8/31	19A	1.67	400	8900	126	47	1.67	28.1
8/31	21A	1.88	100	7500	260	33	1.25	26.4
8/27	23A	1.67	900	9300	0	362	1.68	215

Notes: Elapsed test time varied due to tow speed. First loss speed = 1.4 knots for tests 19A and 21A. First loss speed = 1.25 knots for test 23A.

4.4.7 Data Quality

Instrumentation calibration is discussed in Appendix D. Due to time constraints, no replications of the test runs were made. Also, different speeds were not run for a common oil preload and oil discharge rate so data can not be plotted against speed. At best, this test gives three data points that can be used to estimate what the oil loss rate might be in actual service.

5.0 NOFI 600S OILBOOM TESTS

5.1 Oil Loss Tests

5.1.1 Objective

The objective of these tests were to determine the first loss tow speed and the first gross-loss tow speed under various wave conditions. The first loss tow speed is the speed at which droplets of oil first begin to escape under the oil boom. The first gross loss tow speed is the speed at which large amounts of oil begin to be lost from under the oil boom. Determination of both oil loss speeds is subjective based on observations using an underwater camera. The first loss speed is easy to determine. The first gross loss speed is also much easier to determine than might be expected because the increase in oil loss rate at first gross loss speed is very dramatic.

5.1.2 Procedure

These tests were conducted in the same manner that Phase 1 tests for the Vee-Sweep were conducted. A skimmer was not used. Tests were conducted with and without the bottom feather netting on the oil boom.

The 600S boom was first rigged to the tow points at the same position used in the Vee-Sweep tests. The towing plates and load cells were the same as those used in the previous tests. A mouth gap of 16.8 meters (55 feet) was initially used. The oil used for the tests was a medium viscosity oil having the tradename Hydrocal 300® and produced by Calumet Lubricants Co. The outside temperature drop dictated the change to this less viscous oil. Hydrocal has the following advertised characteristics:

Viscosity	140 cSt @ 25°C
Specific Gravity	0.899

An effort was made to keep the boom bladder pressure constant throughout the test series. The test series was shortened from that used for the Vee-Sweep to include calm water, 2.5 second regular waves, and harbor chop both with and without the bottom netting.

The boom was initially tested with a preload of 0.38 M^3 (100 gallons) of oil, test 30A. The first loss speed was difficult to determine due to a significant wake with entrained air behind the boom. This made viewing on the underwater video camera difficult. Also, the first gross loss speed was not reached below 2 knots. At that speed there was a significant hydraulic drop across the boom. The mouth gap was reduced to 14 meters (46 feet) to reduce the wake effects and the test was rerun as test 30A1. In this test, the first loss speed was not very stable with a loss first occurring at 1.3 knots and then stopping. First loss reoccurred at 1.5 knots and the first gross loss occurred at a different point on the boom at 1.85 knots. At first loss speed, there was almost no oil visible on the surface. The boom skirt formed a pocket that held all the oil. The test was repeated with the same preload, test 30A2, with equally bad results.

A decision was made to increase the preload to 1.14 M^3 (300 gallons) to overcome some of the observed difficulties. The calm water tests with netting were repeated with the 1.14 M^3 preload and all other tests were conducted with this preload. With the 1.14 M^3 preload the results were more reasonable and repeatable. Considerable air was still entrained in the wake for all tests making it difficult to determine speeds accurately.

5.1.3 Independent Variables

The only independent variables for this test are the wave conditions and the tow speed.

5.1.4 Test Measurements

The following measurements were made for these tests. The first loss and first gross loss tow speeds were determined by visual observation using the underwater video camera to observe oil flow. Figure 1 shows instrumentation locations which were essentially the same as for the Vee-Sweep tests. All recorded data was taken at a rate of 10 samples/second.

Time
Tow Speed
Wave Height
Boom Angle at the Sweep Mouth
Tension in Each Tension Line
Tow Force
Air and Water Temperature
Wind Speed and Direction

Testing took place on September 28 and 30, 1992 and on October 1st and 6th. High winds prevented testing on the days in between due to natural wave formation in the test tank. Environmental data was collected for each of the test runs and is included in Appendix B. Wave height versus time measurements were made with the wave probe stationary in the vicinity of the tow carriage. Measurements were made before the start and at the end of each run down the test tank. Wave data was collected for 200 seconds both before and after the run.

Regular waves were generated for four minutes before prerun wave data collection began. Harbor chop conditions were allowed to develop for 15 minutes before beginning data collection.

Oil samples were collected and analyzed. The results of this analysis are in Appendix C.

The oil thickness was not determined for these tests.

5.1.5 Instrumentation

The instrumentation for this test is common with the Vee-Sweep tests and is listed in Appendix A.

5.1.6 Analysis of Data

The first loss and first gross loss tow speeds for the test runs with and without bottom netting are shown in Table 7. Table B-6 in Appendix B shows the environmental data associated with both sets of tests.

Wave data is shown in the form of wave amplitude spectra in Appendix B. The wave data were combined to determine the average apparent period and significant wave height for each test run which are shown in Table 7. The critical speed tests discussion explains how these values were computed.

5.1.7 Data Quality

Instrumentation calibration is discussed in Appendix D. The principal results of these tests were visual observations of the first loss and first gross-loss speeds. Table 7 shows the repeatability of these observations between two tests under the same conditions. All data falls within the measurement precision of ± 0.1 knots except for the first loss speed for harbor chop conditions without feather netting. For that case, the difference in speed between runs is 0.2 knots.

The oil for these tests was not heated. The oil was stored at a temperature approximately equal to the air temperature which was a few degrees colder than the water tempeature during these tests. For estimating the

Table 7. NOFI 600S Oilboom Summary.

Date	Test No.	Wave Condition	$H_{1/3}$* (inches)	A.A.P.** (sec)	1st Loss Speed (knots)	1st Gross Loss Speed (knots)	Oil Preload (gal)	Viscosity (cSt)
Oilboom With Netting								
9/28	30A	Calm	0	NA	1.4-1.5	2+ Gross speed not attained	100	870
9/30	30A1	Calm	0	NA	1.5	1.8	100	870
9/30	30A2	Calm	0	NA	1.4	1.5	100	870
9/30	30A3	Calm	0	NA	1.3	1.4	300	870
9/30	30A4	Calm	0	NA	1.2	1.4	300	870
9/30	31A	Regular	10.63	3.52	1.3	1.6	300	870
9/30	31B	Regular	5.66	4.64	1.3	1.6	300	870
10/1	34A	Harbor Chop	12.73	1.85	1.3	1.5	300	630
10/1	34B	Harbor Chop	16.77	2.4	1.2	1.5	300	630
Oilboom Without Netting								
10/6	40A	Calm	0	NA	1.2	1.4	300	1050
10/6	40B	Calm	0	NA	1.2	1.4	300	1050
10/6	41A	Regular	8.07	4.47	1.2	1.4	300	1050
10/6	41B	Regular	10.17	4.5	1.2	1.4	300	1050
10/6	44A	Harbor Chop	18.48	2.26	1.1	1.3	300	1050
10/6	44B	Harbor Chop	20.48	2.37	0.9	1.2	300	1050

* - Significant Wave Height
** - Average Apparent Period of Waves

viscosity, an oil temperature slightly higher than air temperature was used to account for the fact that the oil was being distributed on warmer water.

The critical speed test discussion includes details of how the average apparent period and significant wave height were computed. Appendix B includes a discussion of the accuracy of wave spectra. Appendix B also includes a table showing the difference between the waves before the test run and after the test run.

6.0 RESULTS AND CONCLUSIONS

The NOFI Vee-Sweep could be tested with reasonable accuracy only with the 700 mm (27.6 inch) skirt depth. With the 700 mm skirt, the water depth to boom draft ratio is 3.5/1, lower than the recommended 4/1 minimum ratio but reasonably close. The flow velocity under the Vee-Sweep was slightly higher than in the open ocean as a result. The observed critical tow speed, first loss tow speed, and first gross-loss tow speed in the tank are likely to be slightly lower than would occur in the open ocean because of this higher flow velocity under the sweep.

6.1 Vee-Sweep Critical Speed Tests

The mode of failure at critical speed was submergence of the boom apex in all cases. The Vee-Sweep remains stable up to the point of apex submergence. Long period waves, nominally 4.6 second period, had little effect on the Vee-Sweep. Waves of 2.5 second nominal period result in a standing wave inside the Vee-Sweep about 2.4 M (8 feet) forward of the apex. This standing wave had no noticeable effect on Vee-Sweep stability. Waves of 1.6 second period caused significant splash over at the apex well before the critical speed was reached but did not reduce the critical speed.

The measured critical tow speed was 3.4 to 3.6 knots in calm water and small regular waves. The critical speed was only 2.4 knots in harbor chop conditions which is probably due to the increased amplitude of the harbor chop over the regular waves tested.

6.2 Vee-Sweep Oil Loss Speed Tests

The results of the oil loss tests are summarized in Table 8. This table shows the average results measured with and without the skimmer present, with 100 and 900 gallon preloads, and with SUNDEX 8600T and Hydrocal 300 test oils.

Table 8. Summary of Oil Loss Speed Tests (NOFI Vee Sweep).

100 gallon preload (All speeds in knots)				
Test Oil	SUNDEX 8600T		Hydrocal 300	
Wave Condition	First Loss Speed	Gross Loss Speed	First Loss Speed	Gross Loss Speed
Calm	1.4	1.8	1.1	1.4
4.6 sec Regular	1.4	1.6	--	--
2.5 sec Regular	1.5	1.7	--	--
1.6 sec Regular	1.3	1.65	--	--
Harbor Chop	No data	No data	--	--
900 gallon preload (All speeds in knots) (SUNDEX 8600T used)				
	No Skimmer in Sweep		Skimmer Operating	
Wave Condition	First Loss Speed	Gross Loss Speed	First Loss Speed	Gross Loss Speed
Calm	1.25	1.6	1.2	1.55
1.6 sec Regular	1.0	1.35	1.2	1.35

It appears from the results obtained that the following relationships hold. However, the data collected is limited.

- ¤ - First and gross loss speeds are higher with more viscous oils than with less viscous oils
- ¤ - First and gross loss speeds both decrease as the amount of oil in the sweep increases
- ¤ - There is no appreciable difference in measured speeds with a skimmer in the boom or with no skimmer present

6.3 Vee-Sweep Tow Force

The critical speed tests were used to find the tow force on the Vee-Sweep versus speed. Tow forces on one side, in line with the Vee-Sweep side are shown with the critical speed discussion. Total tow force for both sides of the Vee-Sweep, in line with the direction of travel, are listed in Table 9. A 14 degree tow force angle was used to compute the numbers shown. Average force values were taken from the plots in the critical speed section. As this table shows, none of the waves tested had a significant effect on the tow force. The Vee-Sweep was towed with a reduced mouth opening. The tow force should increase somewhat when the sweep is towed with the designed mouth opening. On the other hand, the measured tow force is probably higher than would be expected in the open ocean for the reduced mouth opening due to the bottom blockage effects. This may partially or totally compensate for the extra force expected on a sweep towed with the designed mouth opening.

Table 9. Average Total Tow Force in the Direction of Travel (NOFI Vee-Sweep).

Speed (Knots)	3.5	3.0	2.5
Calm	8540 lbs	5820 lbs	4460 lbs
4.6 sec Waves		5430 lbs	4170 lbs
2.5 sec Waves		5820 lbs	4270 lbs
1.6 sec Waves	8540 lbs	5820 lbs	4080 lbs
Harbor Chop			4080 lbs

The NOFI V-Shaped Vee-Sweep was designed to carry about 50% of the tow force on the lower tension line, 40% on the middle tension line, and 10% on the upper line. However, in service the loads on these lines varies depending on the length of the attachments and on the precise location of the tension line attachments relative to the rest of the Vee-Sweep. There is little likelihood that the designed tensions will be experienced in actual service. For the OHMSETT tests, a towing plate was positioned just before the Vee-Sweep and attached to the Vee-Sweeps G-rings with shackles. The distribution of loads measured was about 82%, 2%, and 16%, respectively, for the bottom, middle and top loads. After the first tension measurements were obtained we considered adjusting all shackles to achieve tension distribution closer to the designed distribution. This was rejected because the tension distribution has little affect on Vee-Sweep performance and because the distribution of loads will vary in service just as much as it did in the OHMSETT test tank.

The load cell on the middle tension line failed before the harbor chop data was collected. Fortunately, this load cell carried the least load and loss of its data was not critical.

6.4 Vee-Sweep Wave Conformance Tests

The results of the wave conformance tests are summarized in Table 10 which is a repeat of Table 5. This table shows the significant wave height and period together with the boom significant motions and periods at 3 locations.

Table 10. Wave Conformance Test Summary (NOFI Vee-Sweep).

Date	Test No.	Tow Speed (Knots)	Press. Sensor Location	Relative Motion		Waves		
				$H_{1/3}$* (Inches)	A.A.P.** (Secs)	Type	$H_{1/3}$* (Inches)	A.A.P.** (Secs)
9/15	14A	1.4	Left Apex	3.36	3.56	Regular	8.47	3.68
			Left 3/4 Point	3.91	4.36			
			Right Midpoint	2.90	3.72			
9/15	15A	1.5	Left Apex	5.60	2.77	Regular	6.79	2.49
			Left 3/4 Point	4.17	2.64			
			Right Midpoint	6.28	2.52			
9/14	16A	1.3	Left Apex	2.46	1.69	Regular	4.66	1.59
			Left 3/4 Point	2.91	1.83			
			Right Midpoint	2.90	1.84			
9/15	17A	1.2	Left Apex	13.05	2.25	Harbor Chop	19.96	2.32
			Left 3/4 Point	10.92	2.59			
			Right Midpoint	10.80	2.66			
9/15	17B	1.0	Left Apex	9.07	2.58	Harbor Chop	13.83	2.36
			Left 3/4 Point	7.43	2.40			
			Right Midpoint	8.77	2.49			

* - Significant Wave Height
** - Average Apparent Period of waves

6.5 Vee-Sweep Oil Loss Rate Tests

Only limited testing was conducted on oil loss rates and results are inconclusive. Table 6 from section 4.4.6 is repeated below as Table 11. This table summarizes the oil loss rate data obtained. It was planned to regulate the oil discharge rate to be equal to the oil loss rate during these tests. This would have required several trial and error runs for each data run. Time did not permit us to proceed with this approach. As a result, the oil discharge rates

Table 11. Oil Loss Rate Test Summary (NOFI Vee-Sweep).

Date	Test No.	Tow Speed (Knots)	Oil Preload (Gals)	Est. Viscosity (cSt)	Oil Discharge Rate (GPM)	Volume of Recovered Oil (Gals)	Recovery Time (Min)	Oil Loss Rate (GPM)
8/31	19A	1.67	400	8900	126	47	1.67	28.1
8/31	21A	1.88	100	7500	260	33	1.25	26.4
8/27	23A	1.67	900	9300	0	362	1.68	215

Notes: Elapsed test time varied due to tow speed. First loss speed = 1.4 knots for tests 19A and 21A. First loss speed = 1.25 knots for test 23A.

were not equal to the oil loss rates and this undoubtedly had some effect on the test results. In test 21A, the initial preload was 0.38 M^3 (100 gallons). The amount of oil in the sweep at the end of this test was 1.51 M^3 (400 gallons) as a result of the excess in oil discharge rate over the oil loss rate. Test 19A started with this 1.51 M^3 as the preload. The quantity of oil in the sweep increased to about 2.16 M^3 (570 gallons) by the end of the run. Test 23A was started with a preload of 3.41 M^3 (900 gallons). The quantity of oil decreased to 2.00 M^3 (540 gallons) by the end of this test. the effect of this variation in oil quantity during the test runs can not be determined from the limited data available. Data collected during the oil loss speed tests shows that the oil loss speeds decrease when more oil is added to the sweep. This indicates that the oil loss rate at a given speed will increase as more oil is added to the sweep. This is demonstrated by the fact that the loss rate increased dramatically when the average amount of oil in the boom was increased from 485 gallons in test 19A to 720 gallons in test 23A. The loss rate changed from 28.1 GPM to 215 GPM. Further testing would have to be done to confirm that this change in representative and not due to experimental variability.

6.6 NOFI 600S Oil Loss Speed Tests

Because the outside temperature was lower for the NOFI 600S tests, the less viscous Hydrocal 300 oil was used for these tests. A 300 gallon preload was used. Tests were made with and without the bottom feather net. First loss and gross loss speeds are summarized in Table 12. The bottom netting appears to have little effect in calm water but does increase first and first gross loss speeds in wave conditions.

Table 12. NOFI 600S Summary

Wave Condition	NOFI 600S with Feather Net			NOFI 600S without Feather Net		
	Viscosity (cSt)	First Loss Speed (knots)	Gross Loss Speed (knots)	Viscosity (cSt)	First Loss Speed (knots)	Gross Loss Speed (knots)
Calm	870	1.25	1.4	1050	1.2	1.4
4.5 sec Regular	870	1.3	1.6	1050	1.2	1.4
Harbor Chop	630	1.25	1.5	1050	1.0	1.25

6.7 Performance Summary

The Vee-Sweep and 600S Oilboom both towed in a very stable manner up to the critical tow speed. The sweep has substantial reserve buoyancy and the apex sank gradually as the tow speed was increased. The shape of the sweep was constant throughout the speed range. The oil loss tests demonstrated that the NOFI Vee-Sweep can contain and concentrate oil at speeds above 1 knots which is a significant improvement over most other boom designs.

APPENDIX A

BOOM TEST INSTRUMENTATION

(Lists of Tables and Figures are on Page A-6)

OHMSETT STANDARD TEST INSTRUMENTATION

The instrumentation described in this appendix is permanently installed at the OHMSETT facility and is used or is available for all tests in the OHMSETT basin.

1. Wavemaker RPM

   The Wavemaker RPM is measured by a pulse-type tachometer sensor mounted on the rotating shaft of the wavemaking machine. Its output was recorded by the data collection system during these tests.

   WaveRPM Sensor:
   AIRPAX Magnetic Pickup Model
   700 87-3040-069
   (With AIRPAX Tachtrol-3 Model
   T77310-1-43-221)

2. Windspeed, Wind direction, Air Temperature.

   The meteorological instruments are located on the roof of the control building at the north end of the OHMSETT basin, approximately 40 ft. above the basin deck. The output of all three instruments is available to the data collection system, and is also displayed on panel meters on the data collection console in the control room.

   Temperature Sensor:
   Model 41350 by R. M. Young Inc.

   Wind Sensor:
   Model 5130 by R. M. Young Inc.

   Anemometer, Wind and Temp Translator:
   Model 26302 by R. M. Young Inc.

3. Carriage Speed and Distance.

   Carriage speed is measured by a pulse-type tachometer sensor which monitors the motion of a wheel which is attached to the main bridge and which runs on the basin deck. The output was recorded by the data collection system during these tests, and is displayed in the main bridge house and on the control console in the control room.

   Carriage distance is measured by a position encoder which records the revolution of the same wheel used for measuring carriage speed. The output was recorded by the data collection system during these tests, and is displayed on the control and data collection consoles in the control room.

Carriage Speed sensor:

AIRPAX Magnetic Pickup for Carriage Speed
Model 70087-3040-012

Carriage Distance sensor:

MITER GEAR BOXES-48 pitch for Carriage Distance into a Computer Conversions Corp Encoder Unit (Model HTMDS90-128-1PHA.)

4. Oil Flow Rate.

Oil flowrate is monitored by a pulse-type transmitter inside the flow totalizer on the main bridge. The output is available to the data collection system and was recorded by that system during these tests. It is also displayed on the data collection console in the control room.

Flowrate sensor:

VEEDER-ROOT Pulse Transmitter Model 7671.

5. Basin Water Level.

The basin water level is monitored continuously by a hydrostatic sensor mounted on the bottom of the tank.

Water Level sensor:

DRUCK Pressure Gage Model PTX 160/D
5 PSI 9 Range
S/N 3045/867

6. Basin Water Temperature.

The water temperature is monitored continuously by a thermocouple-type electronic temperature probe. The output is displayed on a meter in the data collection console.

Water Temperature sensor:

OMEGA RTD Probe
Model PR-11-2-100-1/4-6E.

7. Wave Height.

Wave height is measured by two instruments. One is an acoustic altimeter specifically designed for use in air. It is mounted a support structure extending from the south side of the main bridge at a nominal height of 120 inches above the mean basin water surface level. The other sensor is a capacitive wave sensor staff. It is mounted directly to the south side of the main bridge. The output of both sensors is available to the data collection system, and was recorded by that system during these tests.

Sonic Wave Height sensor:

Datasonics Sonar Altimeter, Air, 27 Khz,
Model PSA 900-A, Serial Number 335.

Capacitive Wave Height sensor:

Drexelbrook 10 ft. capacitive wave staff.

8. Video Cameras.

Testing is recorded by an above-water video camera mounted on the north side of the main bridge at about 6 ft. above the water surface, by an underwater video camera mounted on a support beam from the auxiliary bridge at a depth of 4 ft. below the water surface, and by a hand-held portable camera. The fixed cameras have remote-controlled zooming and panning and a choice of automatic or manual exposure control.

Above Water: Pulnix TMC-574 Miniature CCD color camera
Below Water: Pulnix TMC-574 Miniature CCD color camera
Portable: Panasonic SVHS color camera Model AG 450

9. Still Camera.

A standard 35mm camera is available for recording details of testing and was used during the NOFI Vee-Sweep tests.

Camera: Canon 35MM automatic exposure, zoom lens.

SPECIALIZED INSTRUMENTATION FOR THE NOFI BOOM TEST

The instrumentation described in this appendix was used specifically for the NOFI Vee-Sweep tests.

1. Force Gauges.

   Towing force was measured by two METROX™ load-cell force gauges on each of the two main tow cables. The output of all four force gauges was available to and was recorded by the data collection system.

2. Pressure Probes.

   Four DRUCK™ hydrostatic pressure transducers were placed at various locations along the skirt of the NOFI Vee-Sweep. Their output was recorded by the data collection system.

3. Oil Thickness.

   The thickness of oil layers on the water was measured by an acoustic oil thickness probe mounted on the NOFI Vee-Sweep at a depth of approximately 60 inches.

4. Boom Angle.

   Boom angle was measured by an inclinometer which was read visually by test personnel during the towing of the NOFI Vee-Sweep.

Table A-1, which follows, summarizes the data sources for data collected by the data collection system. Data from all listed sensors was recorded at 10 Hz.

Table A-1 NOFI Test Apparatus List.

NOFI TEST APPARATUS LIST			
CHANNEL NO.	CHANNEL NAME	SENSOR	MODEL NO./ SERIAL NO.
1	Bridge Speed	AIRPAX™ Magnetic Pickup	Model 70087-3040-013
2	Bridge Distance	COMPUTER CONVERSIONS CORP. Encoder Unit	Model HTMDS90-128-1PHA
3	Pressure Sensor #1	DRUCK™ Pressure Sensor	S/N 4004
4	Pressure Sensor #2	DRUCK™ Pressure Sensor	S/N 3623
5	Pressure Sensor #3	DRUCK™ Pressure Sensor	S/N 4003
6	Pressure Sensor #4	DRUCK™ Pressure Sensor	S/N 3998
7	Pressure Sensor #5	DRUCK™ Pressure Sensor	S/N 3662
8	Load Cell #1	METROX™	S/N 2667
9	Load Cell #2	METROX™	S/N 661
10	Load Cell #3	METROX™	S/N 660
11	Load Cell #4	METROX™	S/N 2668
12	Wave Height (Capacitance)	DREXELBROOK	10 ft.
13	Wave Height (Sonic)	DATASonics™	Model PSA-900-A S/N 335
14	Wavemaker RPM	AIRPAX™ Magnetic Pickup	Model 70087-3040-067
15	Oil Thickness	Bentech™	Model LM200
16	Oil Distribution Flow Rate	Veeder-Root Pulse Transmitter	Model 7671

LIST OF TABLES

APPENDIX B

ENVIRONMENT, TOW FORCE, AND WAVE DATA

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This appendix includes the following information:

1. Environmental data

2. Tow force plots in waves and wave spectral plots

3. Table of wave analyses for the NOFI Vee-Sweep, showing pre-test, post-test, and averaged values for $H_{1/3}$ and average apparent period.

4. Averaged spectral plots of wave conditions for tests of the NOFI Vee-Sweep.

5. Table of wave analyses for NOFI 600S Oilboom, showing pre-test, post-test, and averaged values for $H_{1/3}$ and average apparent period.

6. Averaged spectral plots of wave conditions for tests of the NOFI 600S Oilboom.

7. Wave conformance data for the NOFI Vee-Sweep: Averaged spectral plots for pressure sensors #2 (right midpoint), #4 (left apex), and #5 (left 3/4 point).

Table B-1. Critical Tow Speed Tests Weather Data.

DATE	TEST#/FILE NAME	WIND DIRECTION AVE	WIND DIRECTION MAX	WIND DIRECTION MIN	WIND SPEED AVE	WIND SPEED MAX	WIND SPEED MIN	TEMP °F H_2O	TEMP °F AIR
8/13	W01T1A	100	160	57	12	19	0	77.1	
8/13	W01T1B	155	225	98	8	15	0	77.1	
8/13	W01T2A	122	192	67	9	14	0	77.6	75
8/13	W01T2B	137	263	20	10	16	1	77.6	74
8/13	W01T3A	72	--	--	7	--	--	--	74
8/14	W01T3B	71	125	35	10	15	4	75.6	67
8/14	W01T3B1	89	134	43	11	16	6	75.9	68
8/14	W01T4A	80	120	33	11	17	0	75.9	68
8/14	W01T4B	96	134	51	13	18	0	75.9	68
8/14	W01T4B1	97	142	45	10	16	0	75.9	68
8/14	W01T5A	117	186	52	8	14	0	76.0	69
8/18	W01T5B	118	166	49	7	11	0	76.0	69

Table B-2. Oil Loss Speed Test Phase 1 - Weather Data.

DATE	TEST#/FILE NAME	WIND DIRECTION AVE	MAX	MIN	WIND SPEED AVE	MAX	MIN	TEMP °F H_2O	AIR
8/18	W01T6A	8	358	2	4	6	2	72.2	73
8/18	W01T6B	13	358	2	4	7	0	71.7	75
8/19	W01T7A	57	354	14	7	15	0	73.5	81
8/19	W01T7B	265	328	178	6	13	2	73.7	–
8/20	W01T8A	16	358	2	8	13	4	73.4	69
8/20	W01T8B	23	358	2	6	10	2	73.4	71
8/20	W01T9A	31	355	2	3	7	0	73.9	71
8/20	W01T9B	333	355	2	8	16	0	74.9	76
8/20	W01T9C	310	355	2	6	13	2	74.8	76
8/20	W01T9C1	310	355	2	6	13	2	74.8	76
8/27	W01T9D	28	355	2	4	8	0	79.6	81
8/27	W01T9D1	28	355	2	4	8	0	79.6	81
9/15	W01T10A	155	229	95	8	14	2	74.5	73
9/15	W01T10B	155	229	95	8	14	2	74.5	73
9/16	W01T25A	289	354	237	5	9	2	73.8	76
9/16	W01T25B	289	354	237	5	9	2	73.8	76

Table B-3. Oil Loss Speed Tests Phase II - Weather Data.

DATE	TEST#/FILE NAME	WIND DIRECTION AVE	MAX	MIN	WIND SPEED AVE	MAX	MIN	TEMP °F H_2O	AIR
8/24	W01T11A	78	124	23	6	10	0	77.1	78
8/25	W01T11B	290	354	2	3	6	0	77.0	84
8/25	W01T11C	210	358	2	3	7	0	77.0	84
8/25	W01T12A	112	172	25	6	10	0	78.1	83
8/25	W01T12B	101	154	14	4	7	0	78.2	85

Table B-4. Wave Conformance Test Weather Data.

DATE	TEST#/FILE NAME	WIND DIRECTION			WIND SPEED			TEMP °F	
		AVE	MAX	MIN	AVE	MAX	MIN	H_2O	AIR
9/14	W01T13A	110	170	60	11	16	5	75	69
9/15	W01T14A	358	358	2	4	8	2	73.4	67
9/15	W01T15A	305	355	3	3	6	0	73.3	64
9/14	W01T16A	113	175	58	10	15	0	74.9	70
9/15	W01T17A	359	358	2	6	11	1	73.9	69
9/15	W01T17B	87	174	31	4	8	0	73.7	70

Table B-5. Oil Loss Rate Tests Weather Data.

DATE	TEST#/FILE NAME	WIND DIRECTION			WIND SPEED			TEMP °F	
		AVE	MAX	MIN	AVE	MAX	MIN	H_2O	AIR
8/31	W01T19A	306	354	2	10	20	0	77.3	80
8/31	W01T21A	283	337	204	11	22	4	80.2	80
8/27	W01T23A	158	221	96	7	12	2	80.8	84

Table B-6. NOFI 600S Oilboom Tests Weather Data.

DATE	TEST #/ FILE NAME	WIND DIRECTION AVE	WIND DIRECTION MAX	WIND DIRECTION MIN	WIND SPEED AVE	WIND SPEED MAX	WIND SPEED MIN	TEMP°F H_2O	TEMP°F AIR
9/28	W01T30A	341	358	2	4	7	0	65.8	66
9/30	W01T30A1	330	358	2	8	17	3	62.8	50.9
9/30	W01T30A2	336	358	2	11	20	2	62.8	51.8
9/30	W01T30A3	340	358	2	11	20	2	62.8	56.1
9/30	W01T30A4	332	358	2	10	20	1	62.8	57
9/30	W01T31A	332	358	2	10	18	2	62.8	56.4
9/30	W01T31B	323	358	2	11	24	3	62.8	56.9
10/1	W01T34A	305	355	2	7	13	2	61	49.3
10/1	W01T34B	334	358	2	10	21	1	61	58.1
10/6	W01T40A	50	113	7	7	12	3	59.5	48.5
10/6	W01T40B	52	101	5	7	13	2	59.5	48.9
10/6	W01T41A	16	358	2	3	8	0	59.5	52
10/6	W01T41B	16	358	2	3	8	0	59.5	52
10/6	W01T44A	33	358	2	3	5	1	59.5	55.9
10/6	W01T44B	43	355	2	3	6	0	59.5	56.1

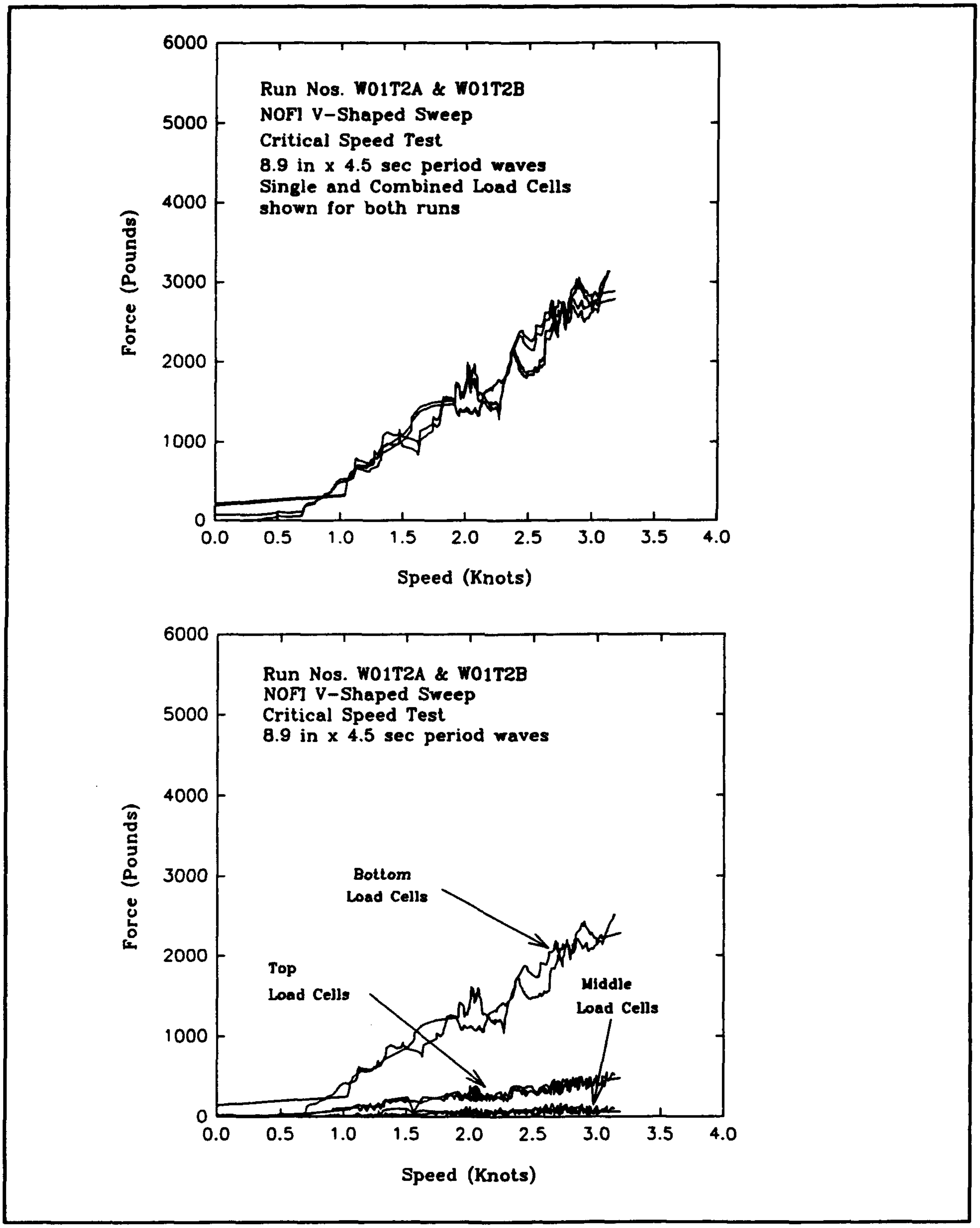
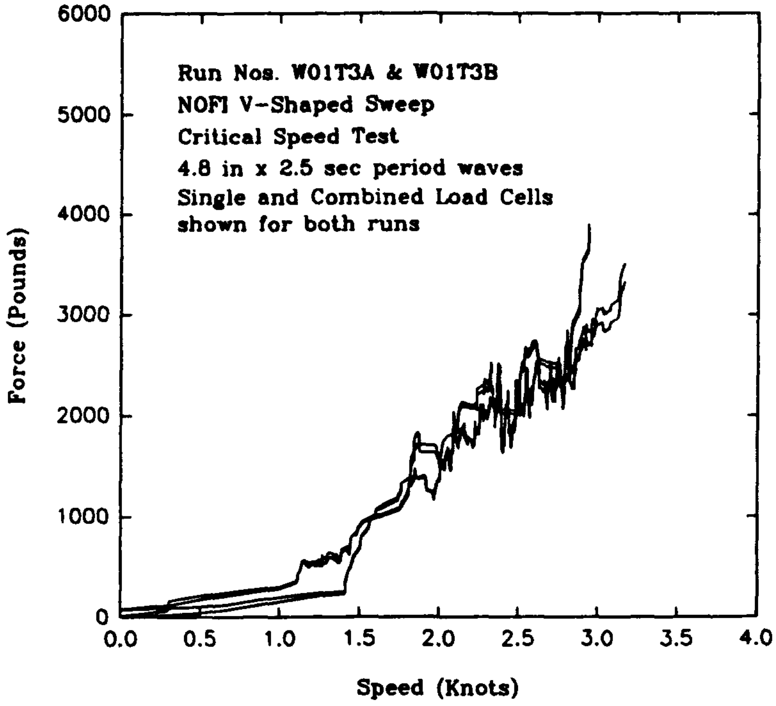


Figure B-1. Tow Force versus Speed - Regular Waves 4.5 Second Period.



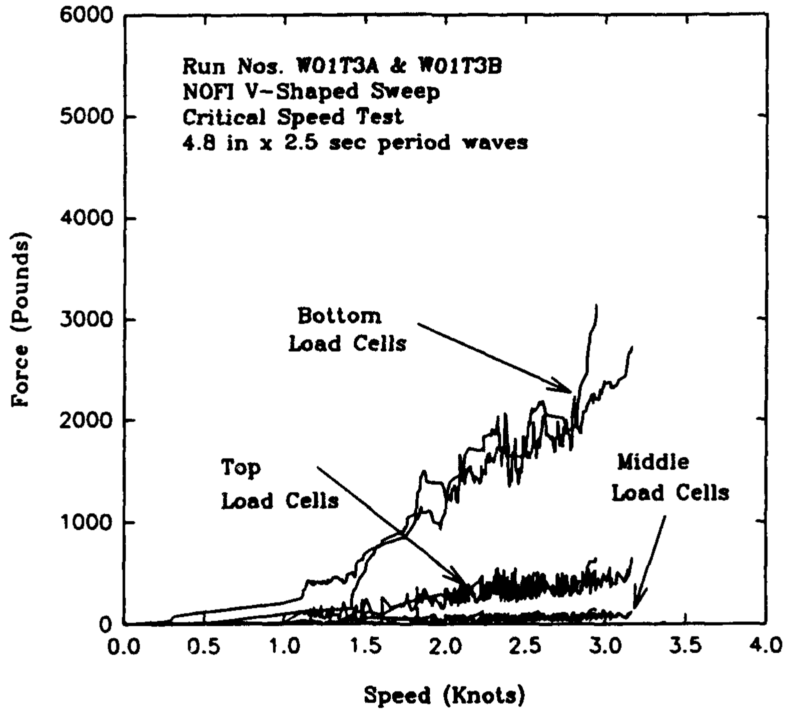
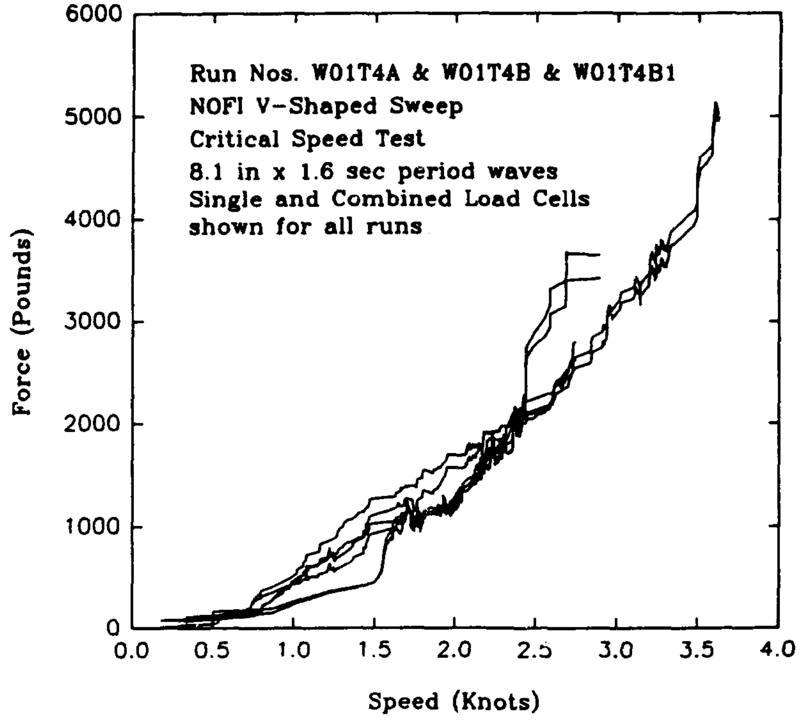


Figure B-2. Tow Force versus Speed - Regular Waves 2.5 Second Period.



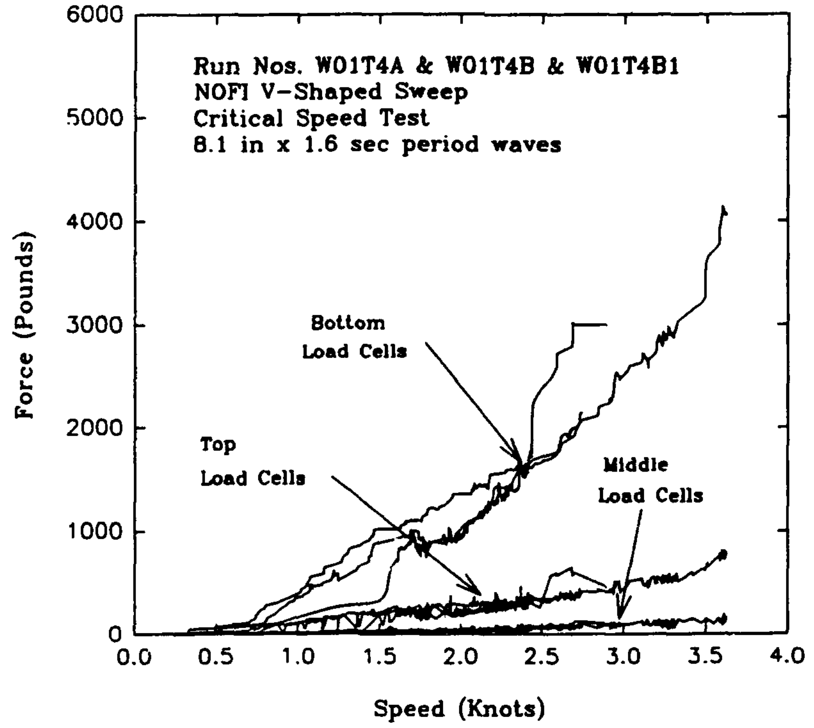
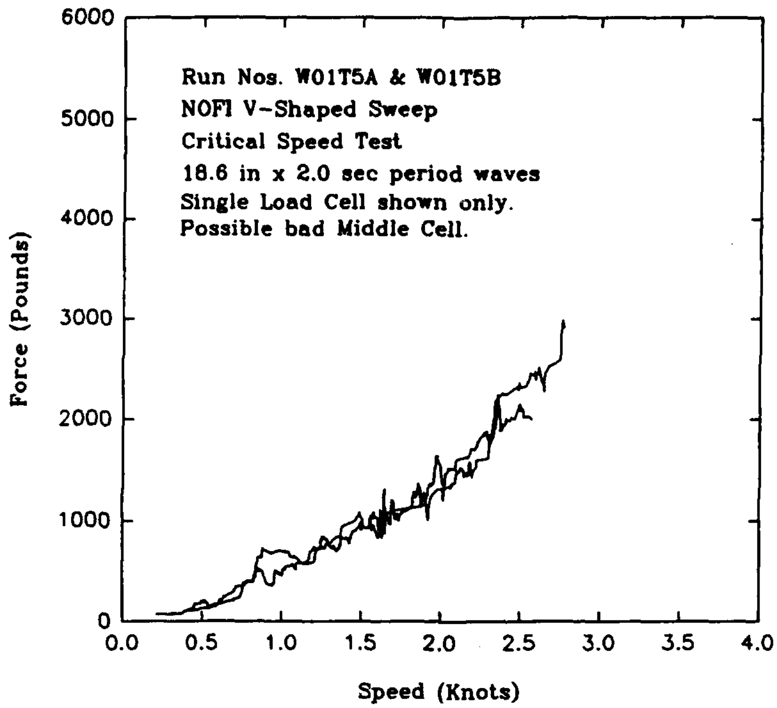


Figure B-3. Tow Force versus Speed - Regular Waves 1.6 Second Period.



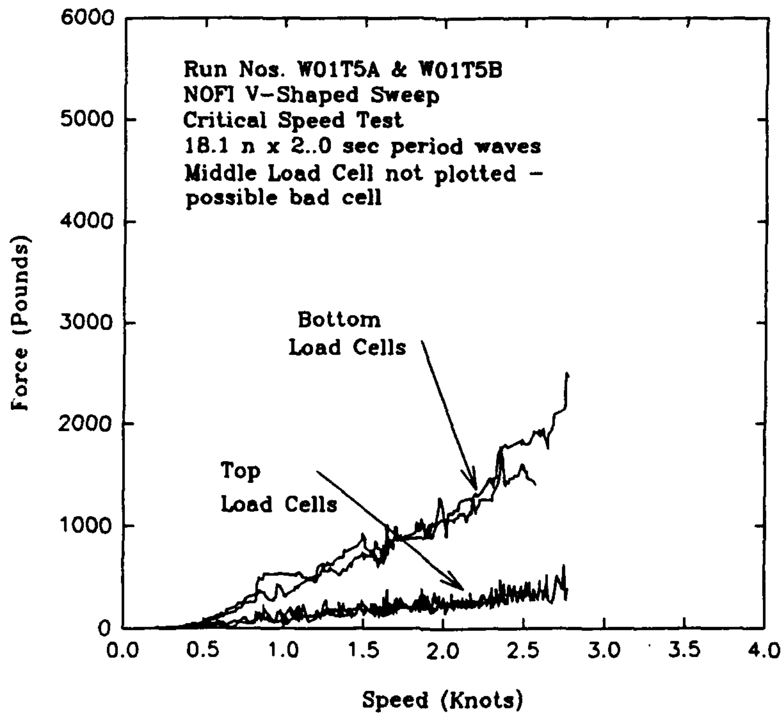
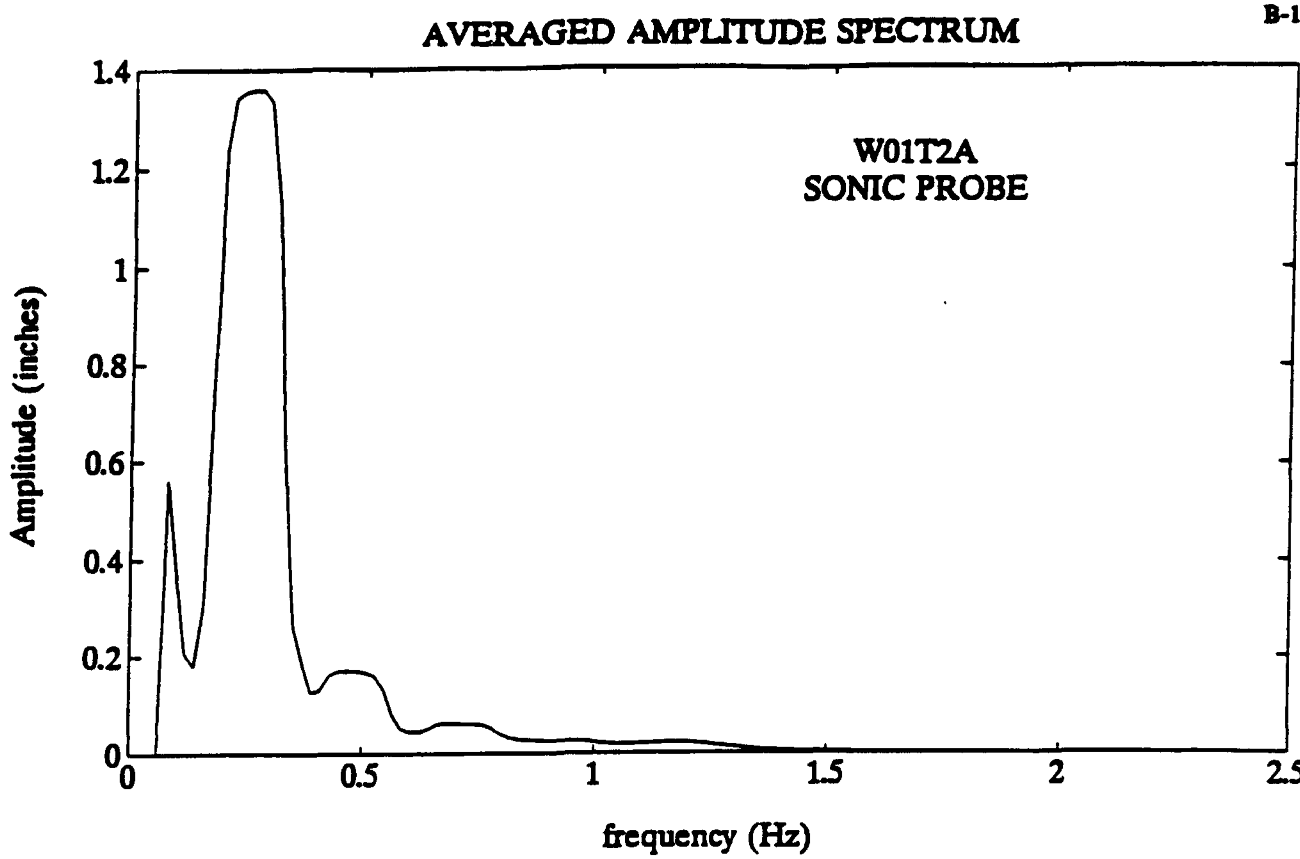


Figure B-4. Tow Force versus Speed - Harbor Chop 2.0 Second Period.

Table B-7. VEE-SWEEP WAVE DATA

FILE/TEST #	AVERAGE H1/3 (inches)	PRE-TEST H1/3 (inches)	POST TEST H1/3 (inches)	AVE APPARENT PERIOD (seconds)	PRE-TEST A.A.P. (seconds)	POST TEST A.A.P. (seconds)
W01T2A	7.66	8.03	6.10	4.52	4.38	4.71
W01T2B	9.26	8.68	9.77	5.04	5.15	4.95
W01T3A	10.5	7.22	11.05	2.54	2.56	2.49
W01T3B	7.61	6.73	8.2	2.45	2.46	2.44
W01T3B1	8.3	7.7	8.8	2.51	2.57	2.42
W01T4A	4.82	4.61	4.83	1.69	2.04	1.44
W01T4B	4.13	3.87	4.26	1.62	1.63	1.51
W01T4B1	4.4	3.93	4.8	1.85	1.71	2.04
W01T5A	13.72	12.5	14.93	2.3	2.39	2.24
W01T5B	14.97	15.78	14.18	2.32	2.36	2.27
W01T8A	6.04	5.27	6.49	2.56	2.61	2.51
W01T9A	4.57	4.45	4.64	1.59	1.79	1.42
W01T9B	4.2	4.0	4.35	1.61	1.74	1.46
W01T12A	4.27	4.09	4.31	1.48	1.59	1.37
W01T12B	4.21	3.86	4.51	1.57	1.61	1.56
W01T14A	8.47	9.25	5.53	3.68	4.5	3.59
W01T15A	6.79	6.34	7.2	2.49	2.5	2.48
W01T16A	4.66	3.93	4.89	1.59	1.71	1.52
W01T17A	19.96	19.11	20.78	2.32	2.36	2.28
W01T17B	15.34	13.83	15.99	2.36	2.25	2.51



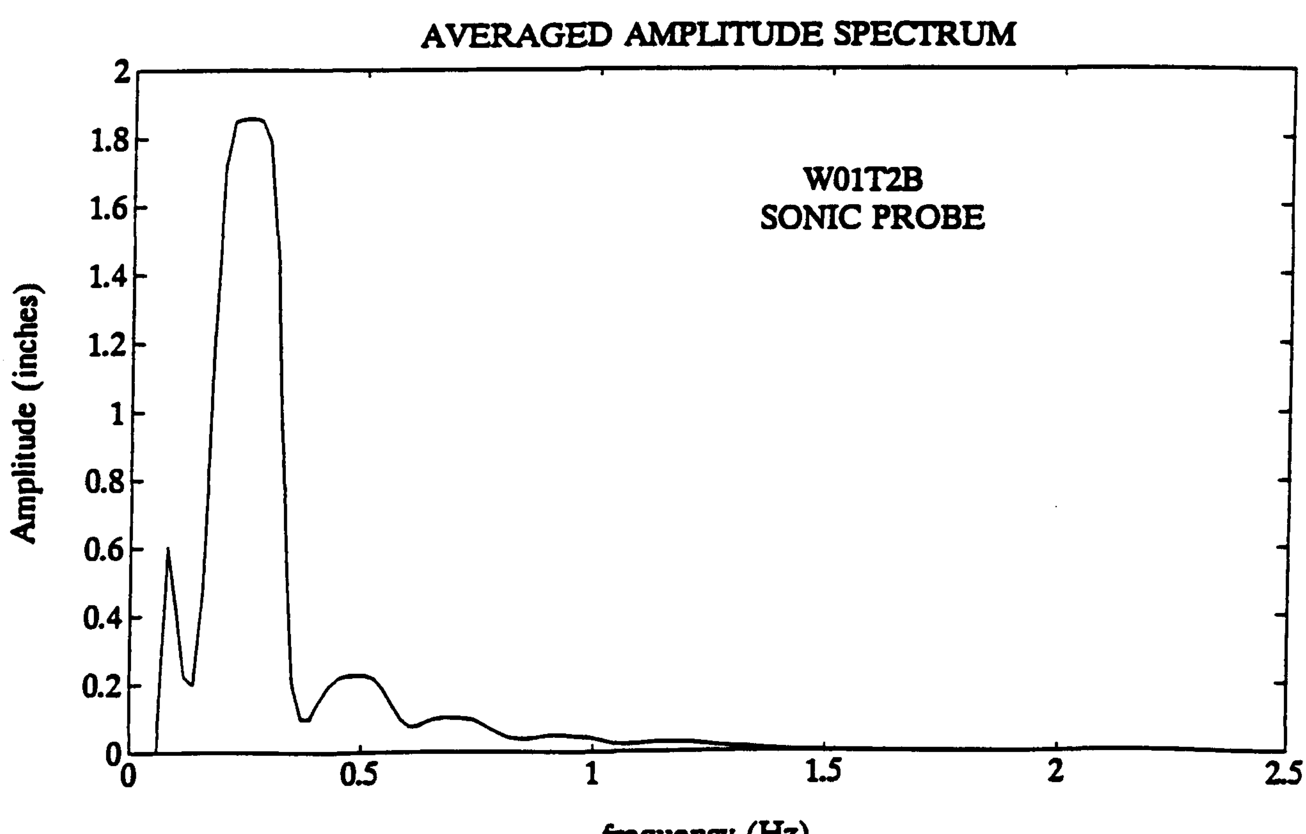
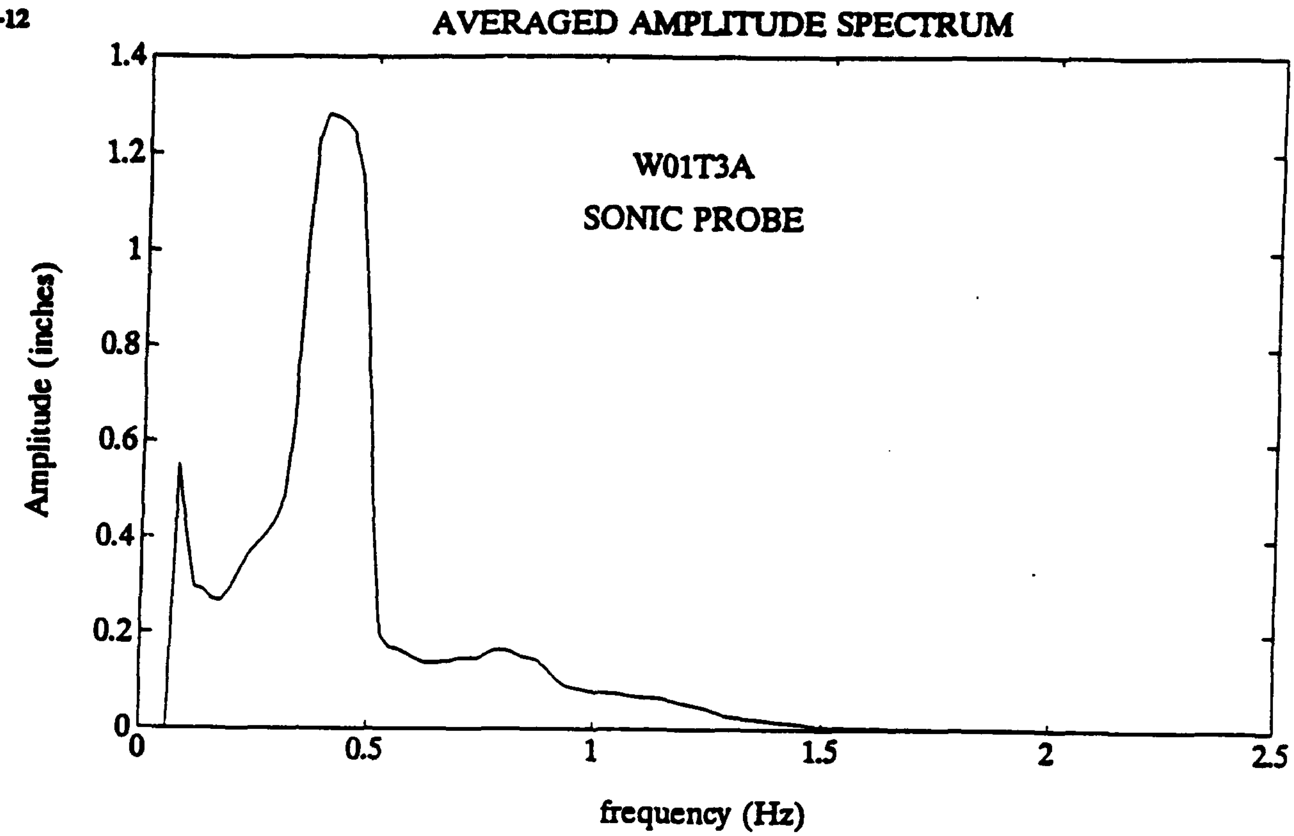


Figure B-5. Wave Averaged Amplitude Spectrum W01T2A & W01T2B



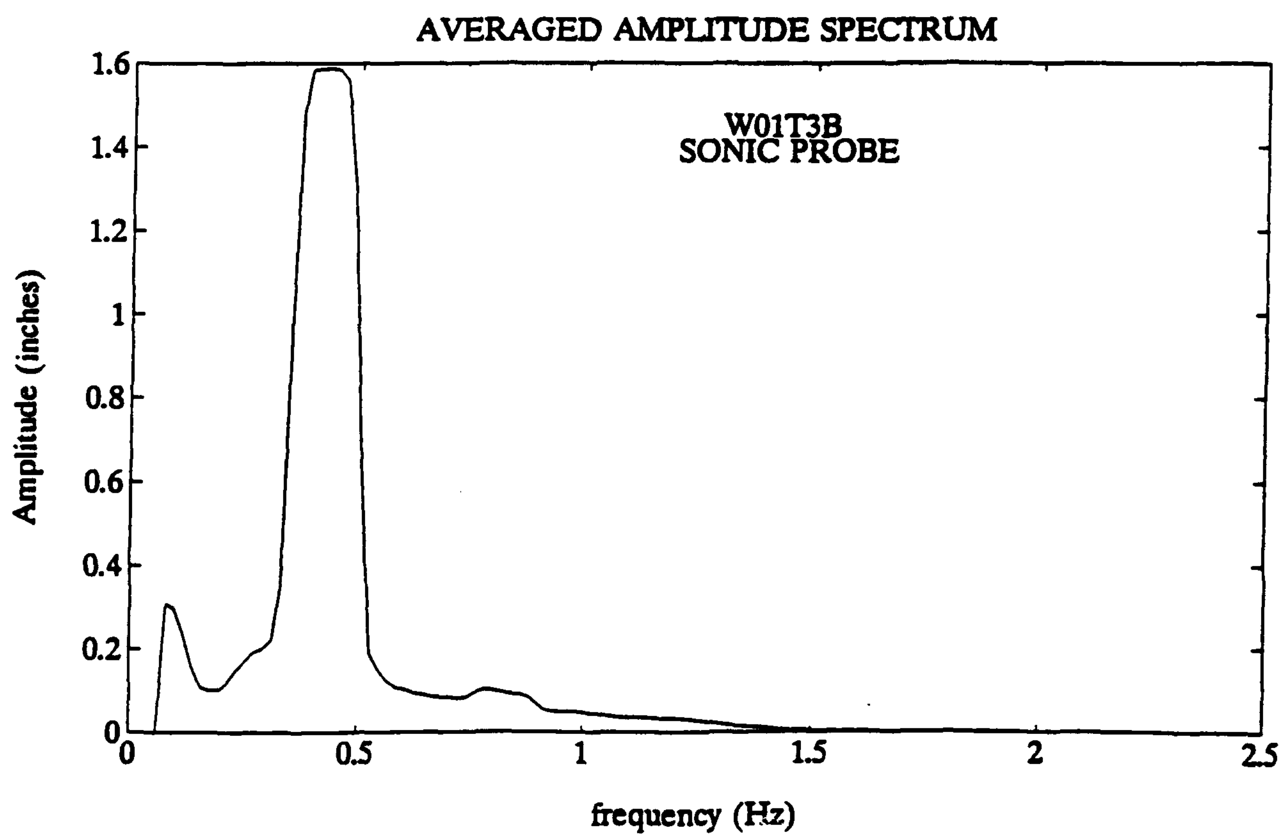
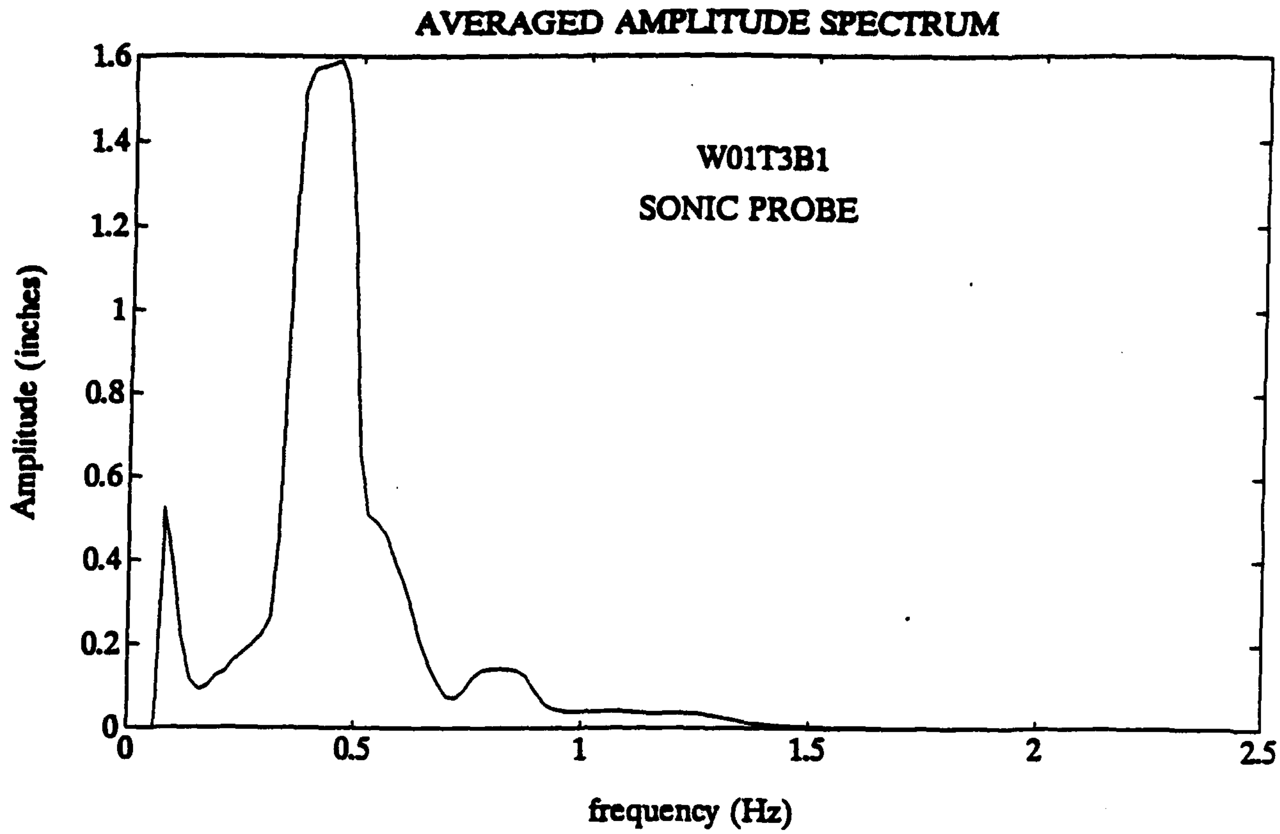


Figure B-6. Wave Averaged Amplitude Spectrum - W01T3A & W01T3B



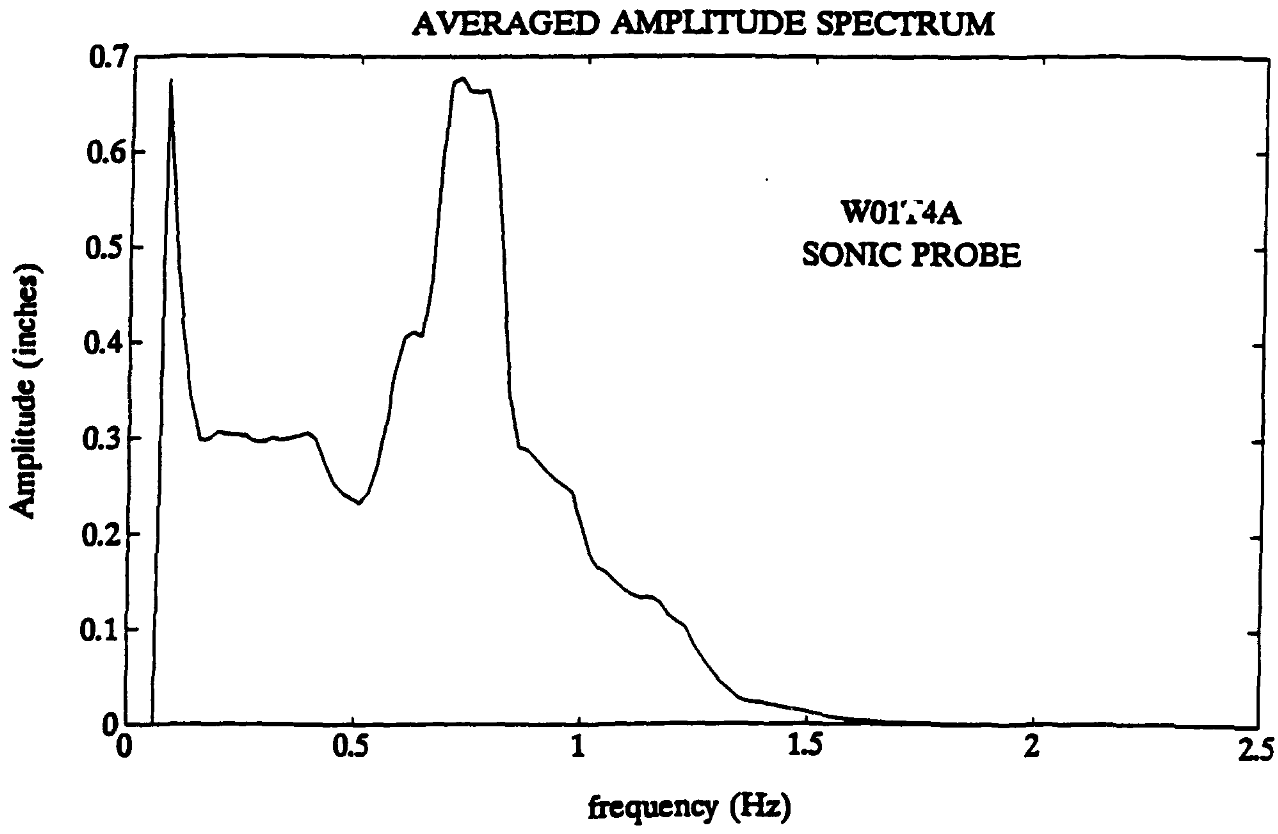
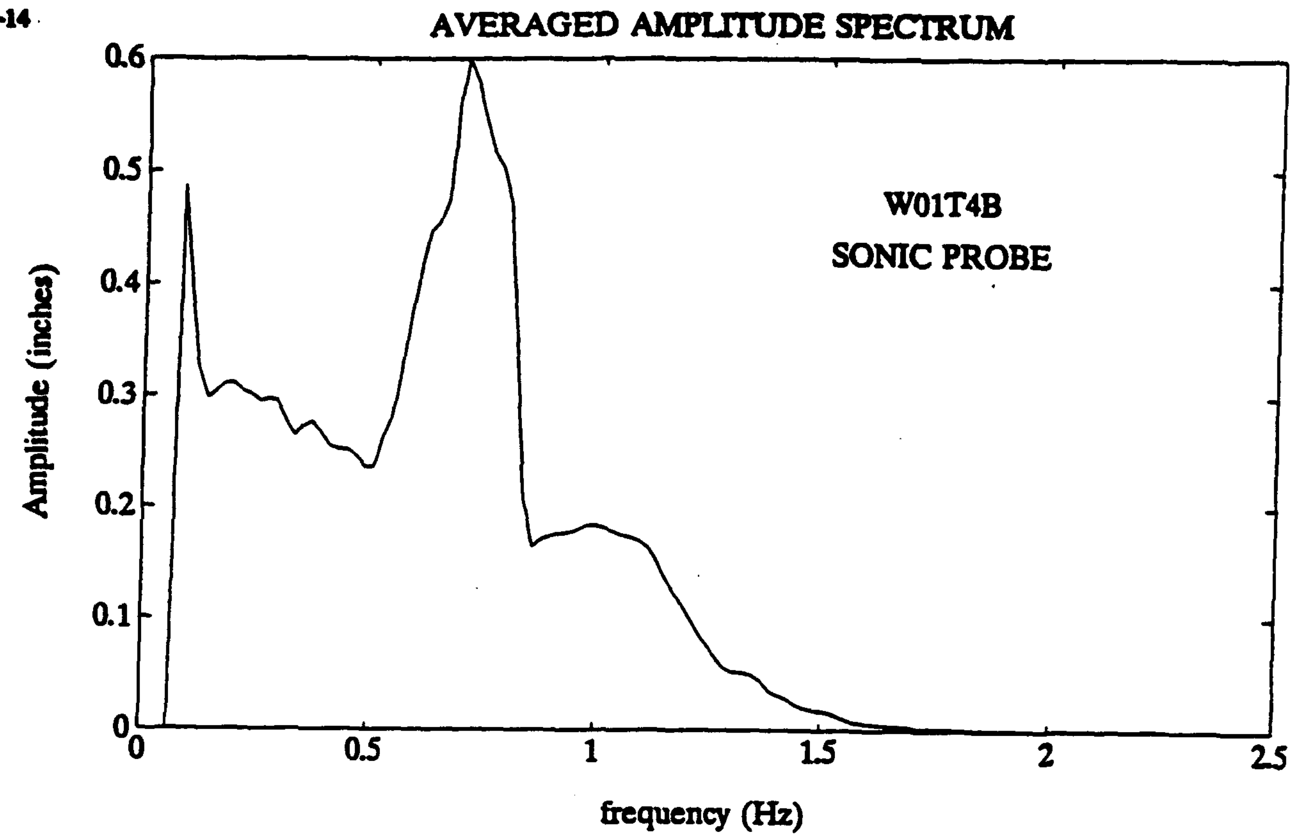


Figure B-7. Wave Averaged Amplitude Spectrum - W01T3B1 & W01T4A



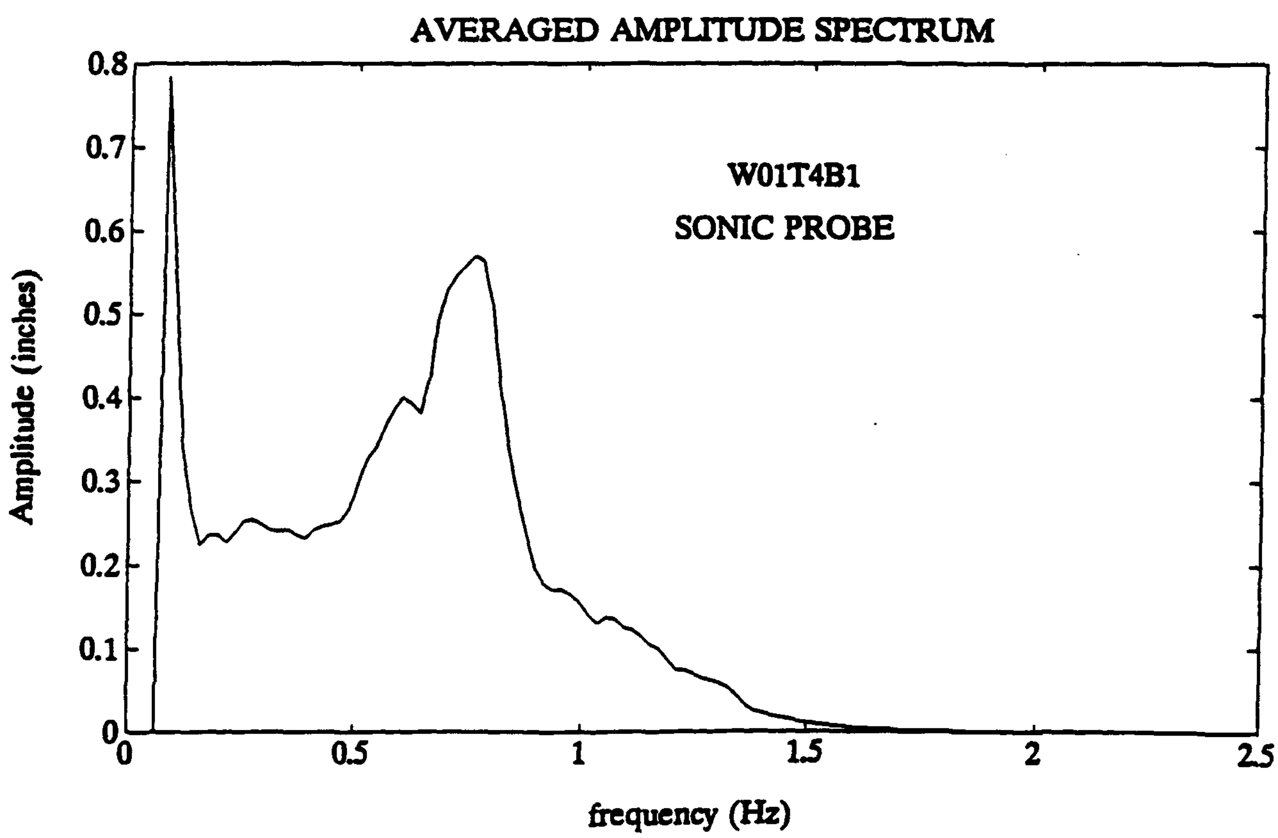
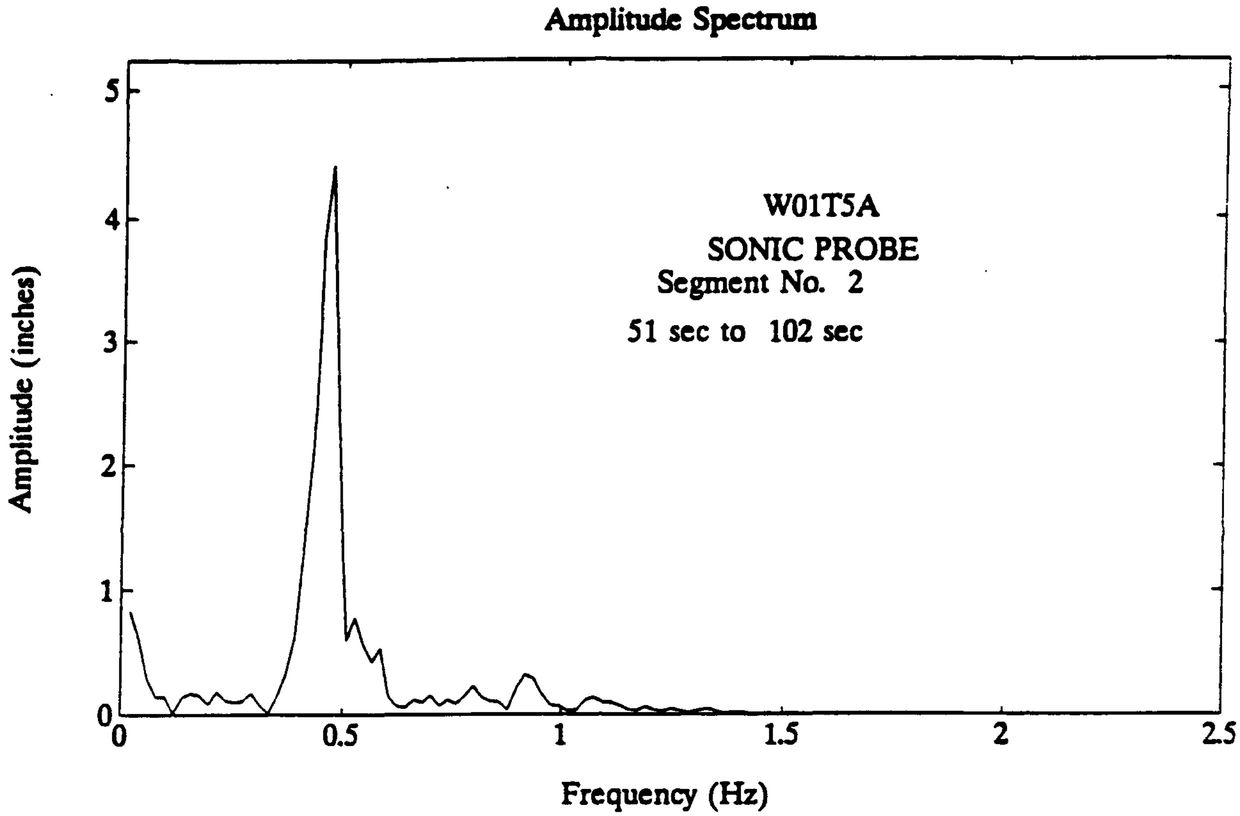


Figure B-8. Wave Averaged Amplitude Spectrum - W01T4B & W01T4B1



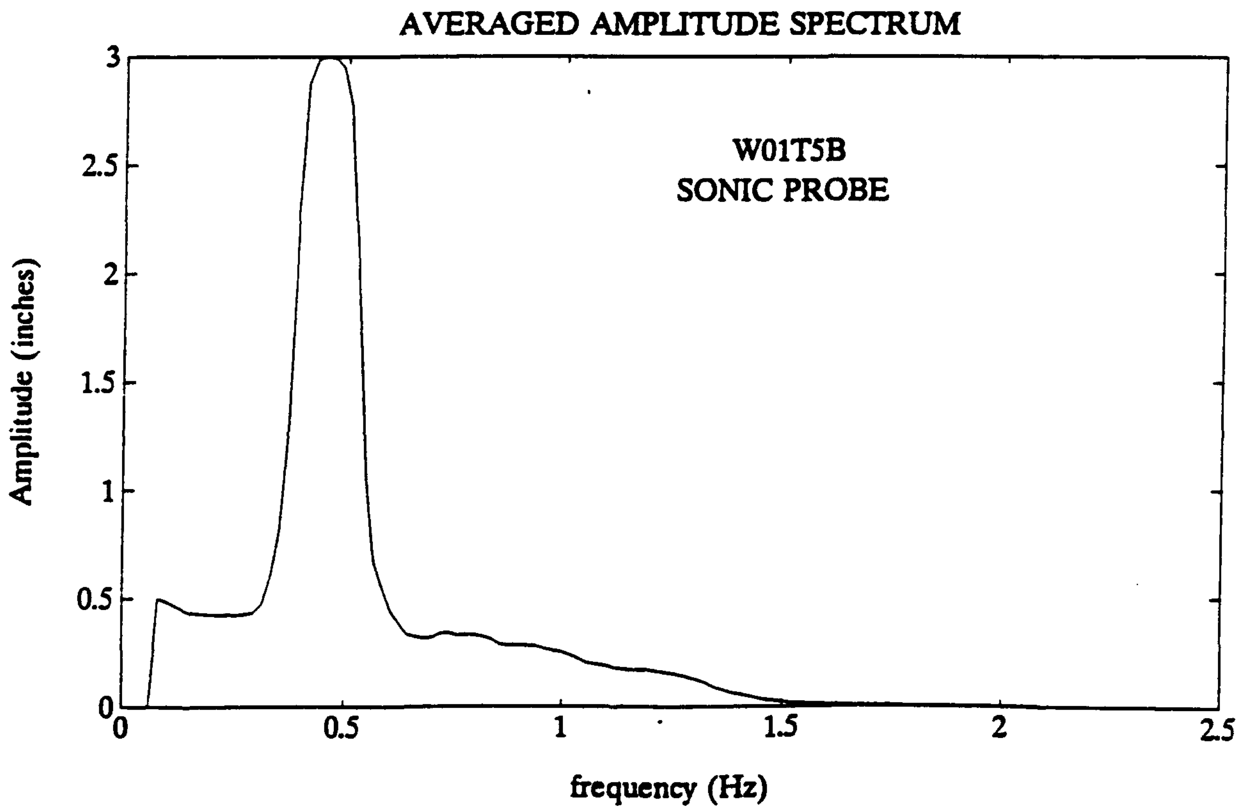
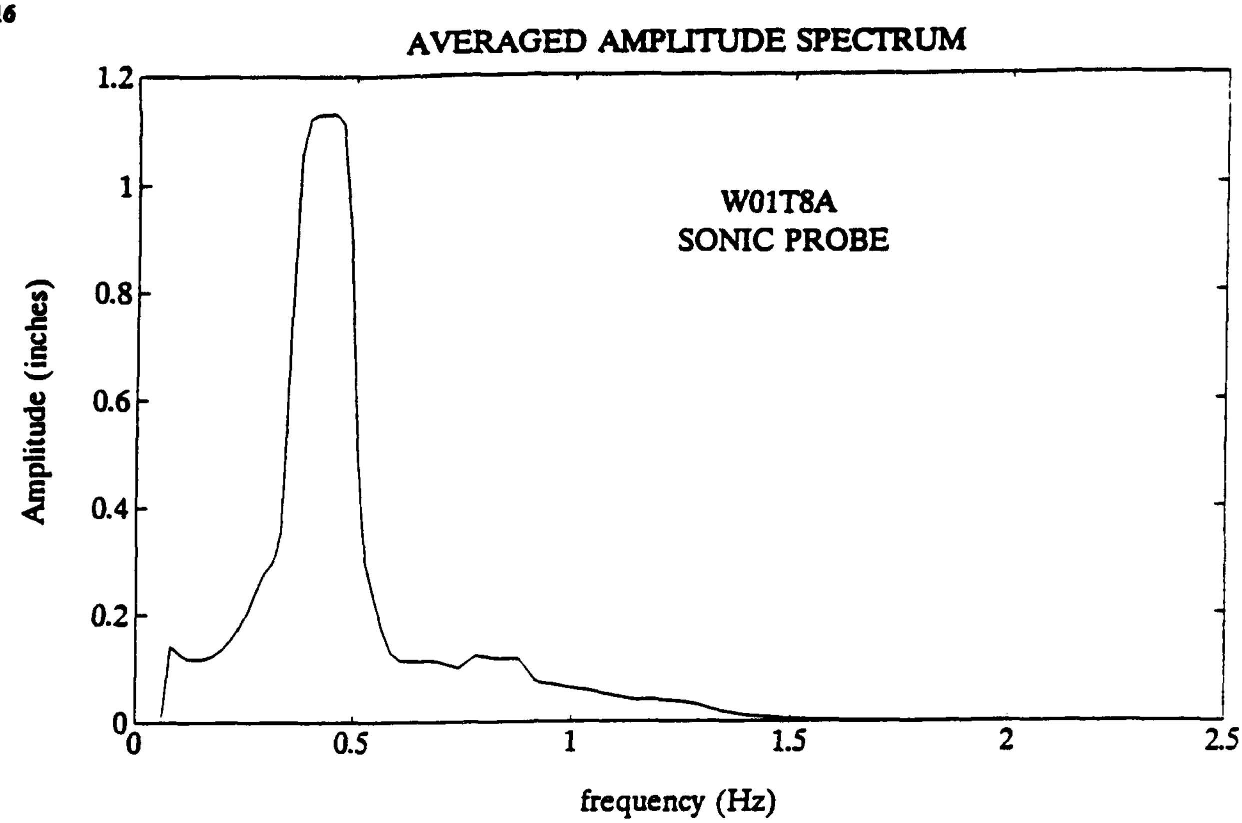


Figure B-9. Wave Averaged Amplitude Spectrum - W01T5A & W01T5B



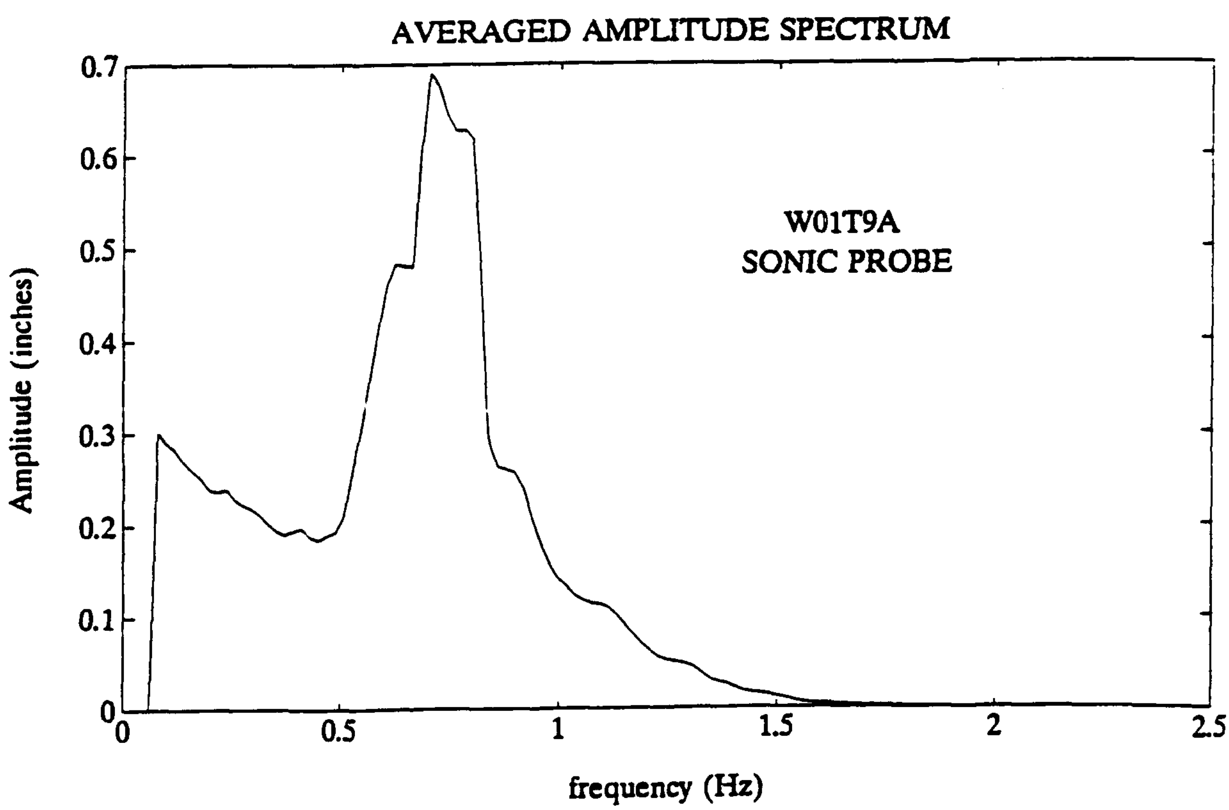
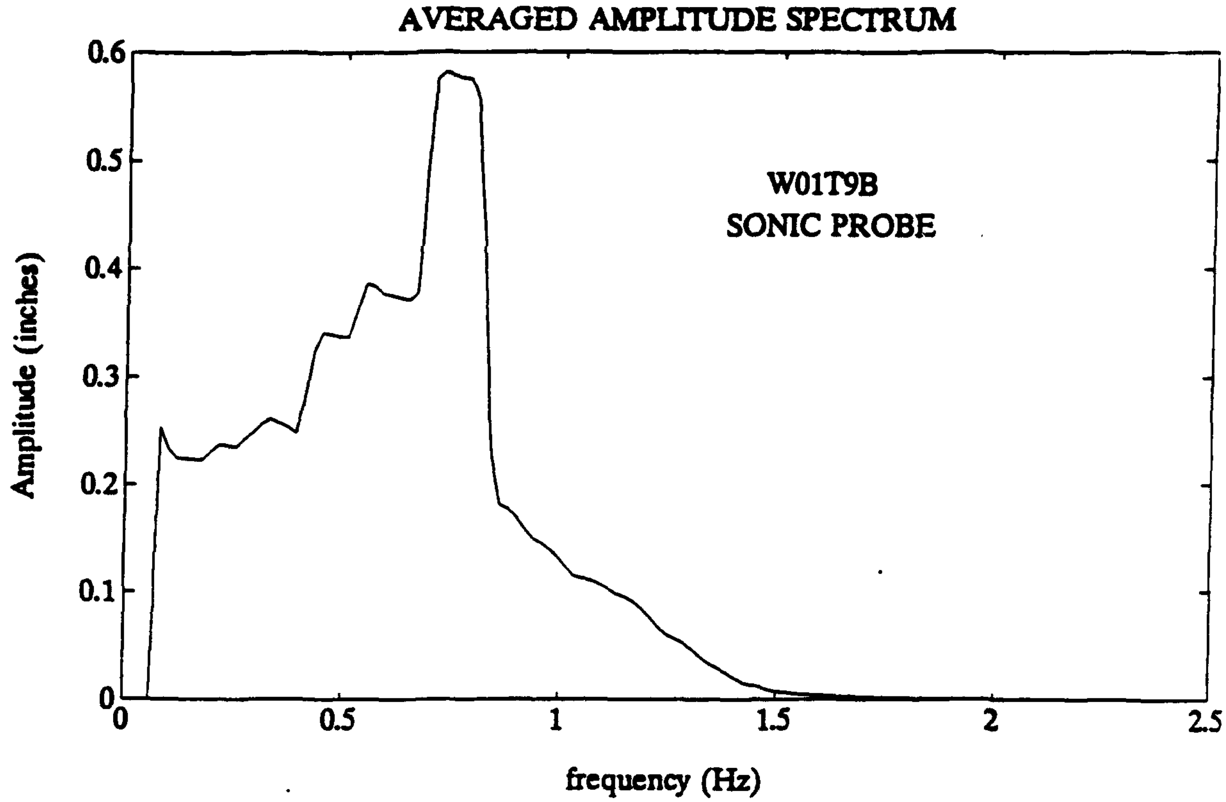


Figure B-10. Wave Averaged Amplitude Spectrum - W01T8A & W01T9A



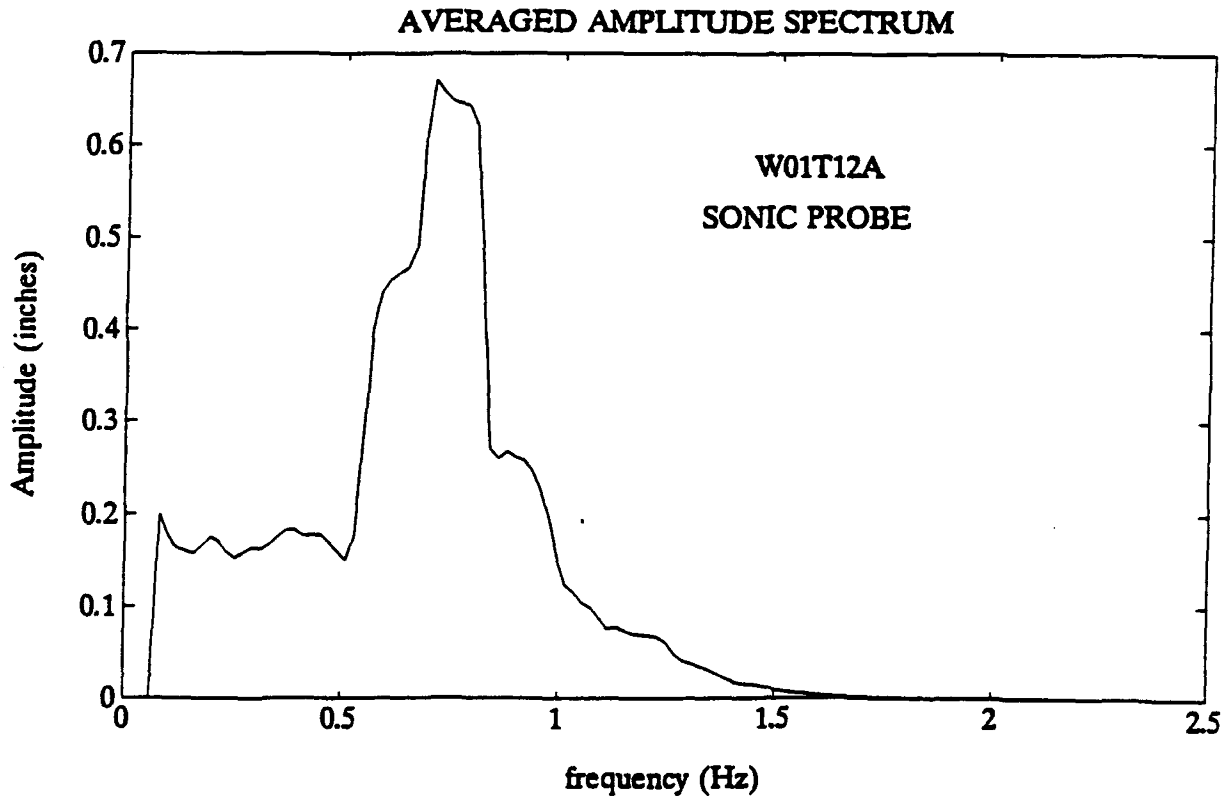
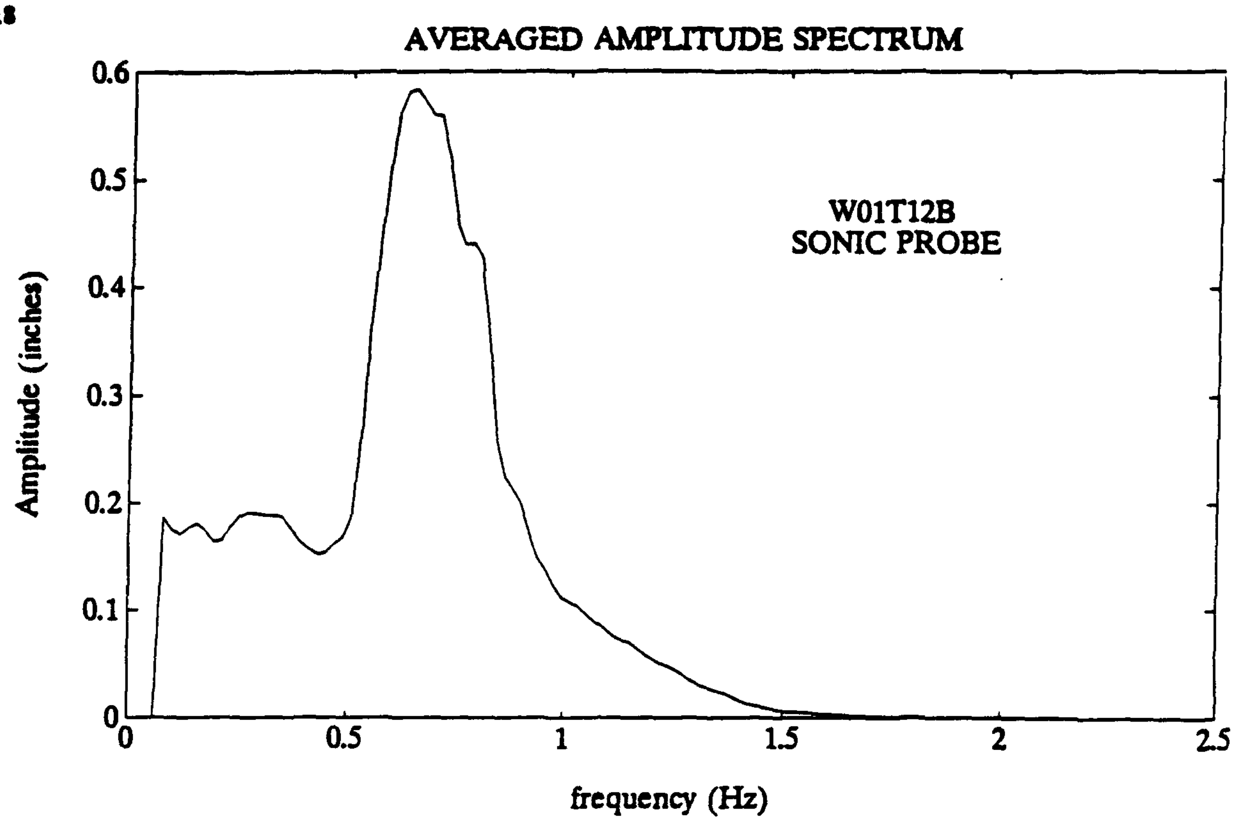


Figure B-11. Wave Averaged Amplitude Spectrum - W01T9B & W01T12A



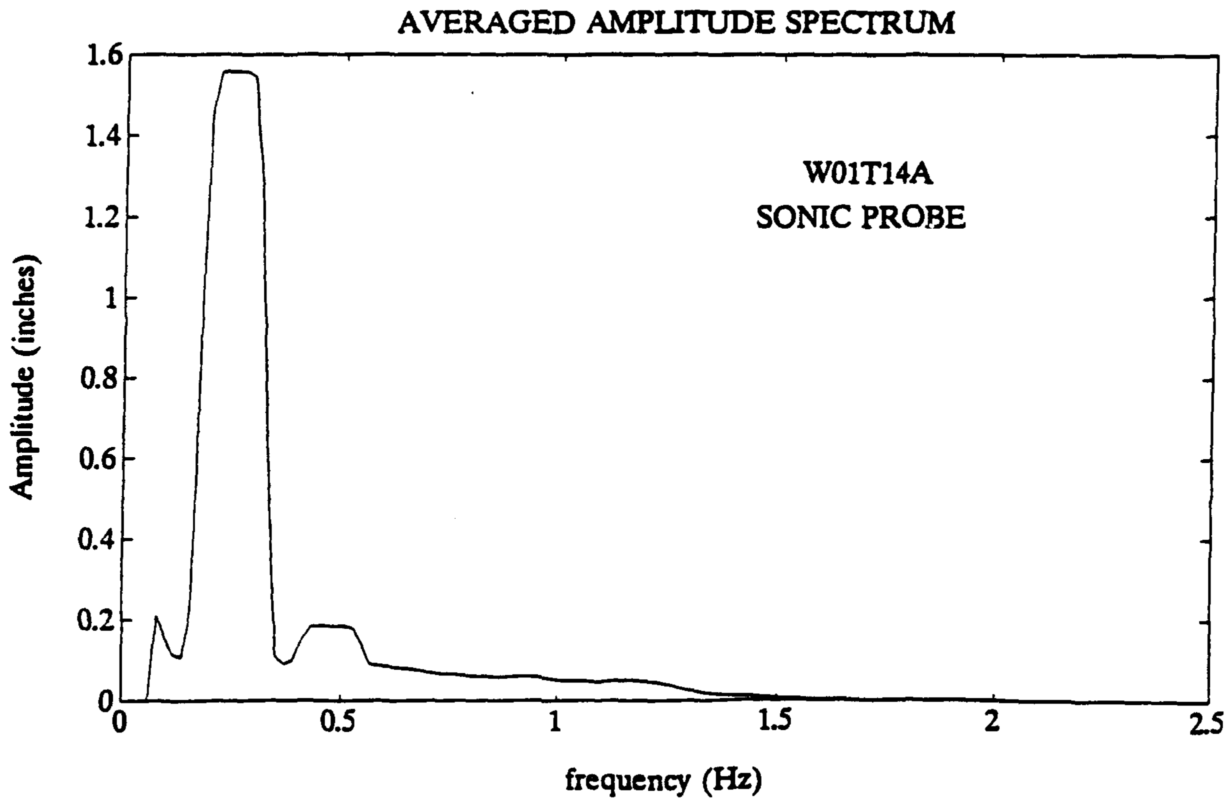
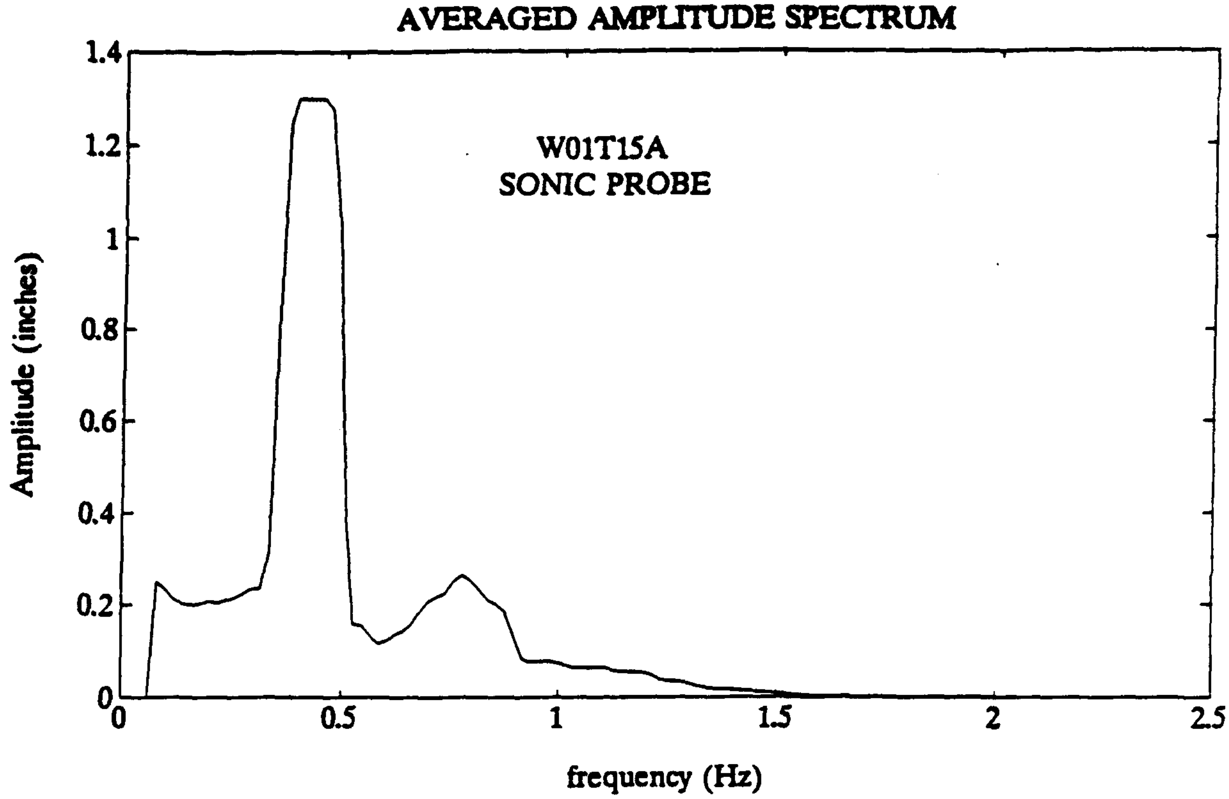


Figure B-12. Wave Averaged Amplitude Spectrum - W01T12B & W01T14A



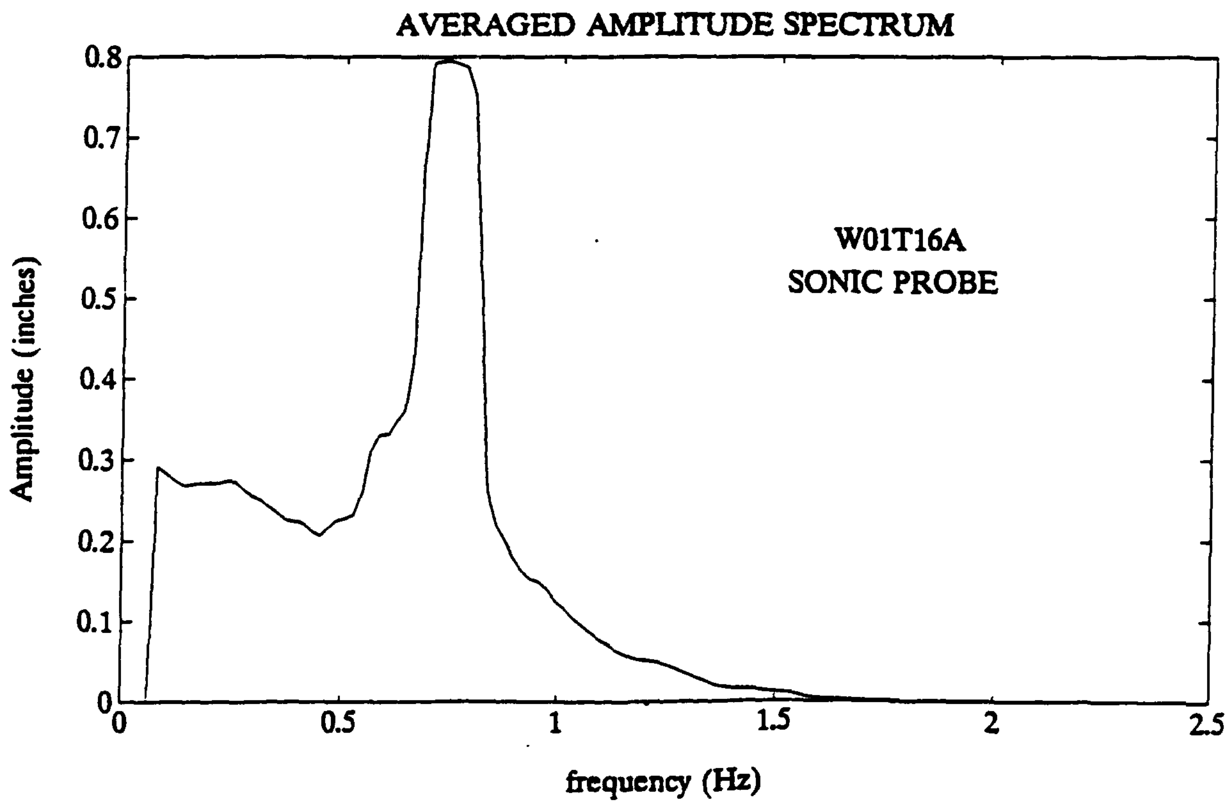
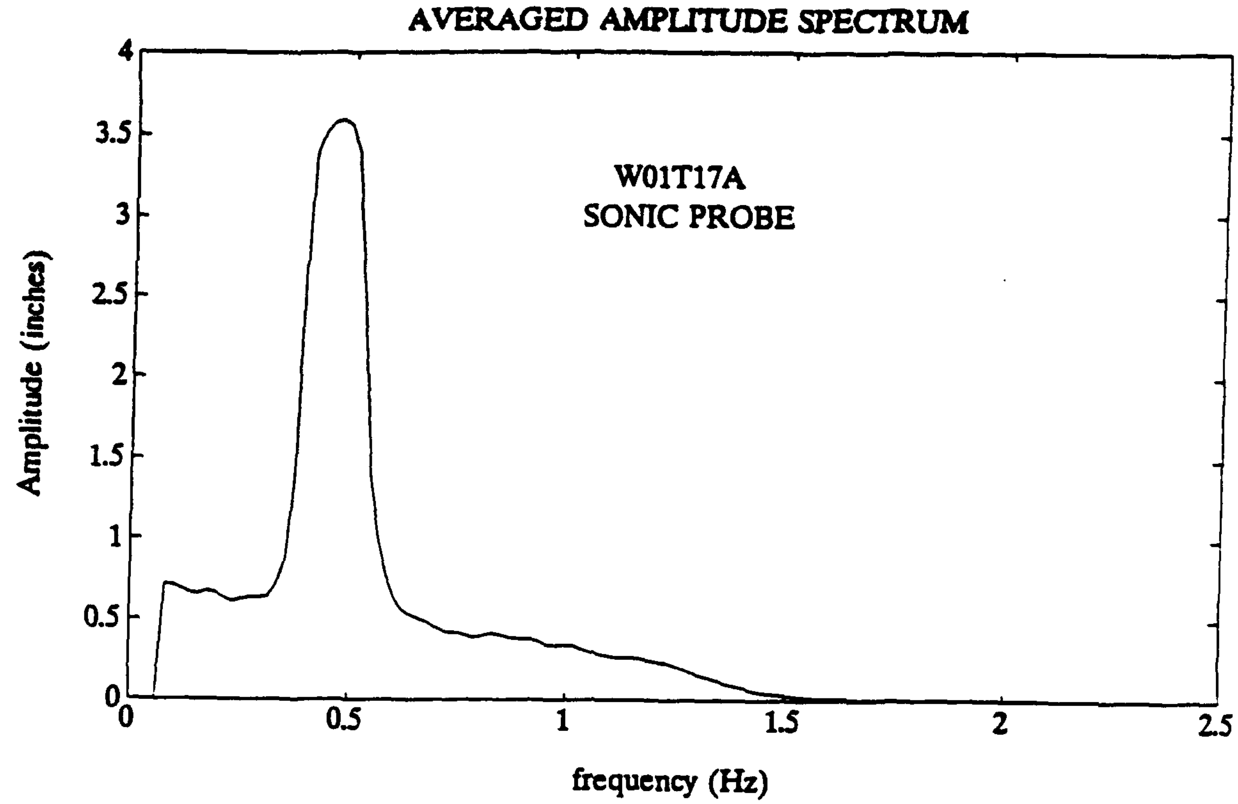


Figure B-13. Wave Averaged Amplitude Spectrum - W01T15A & W01T16A



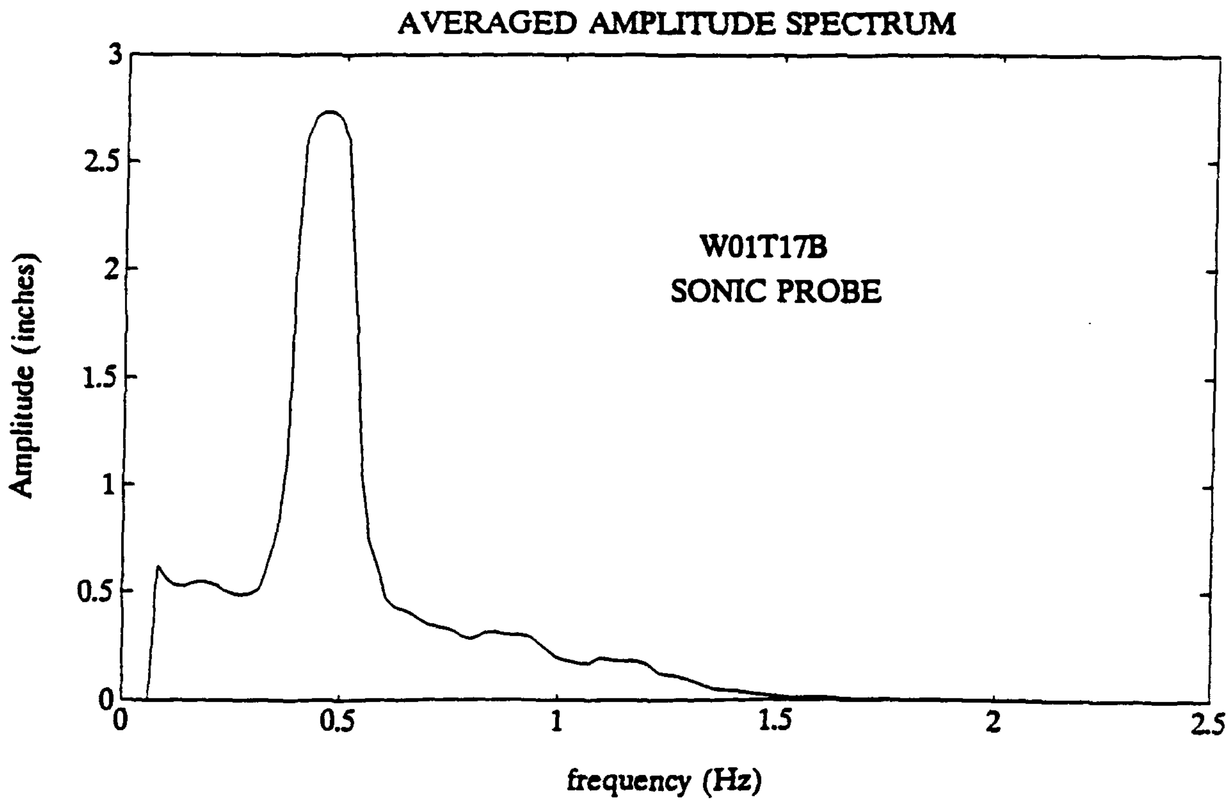
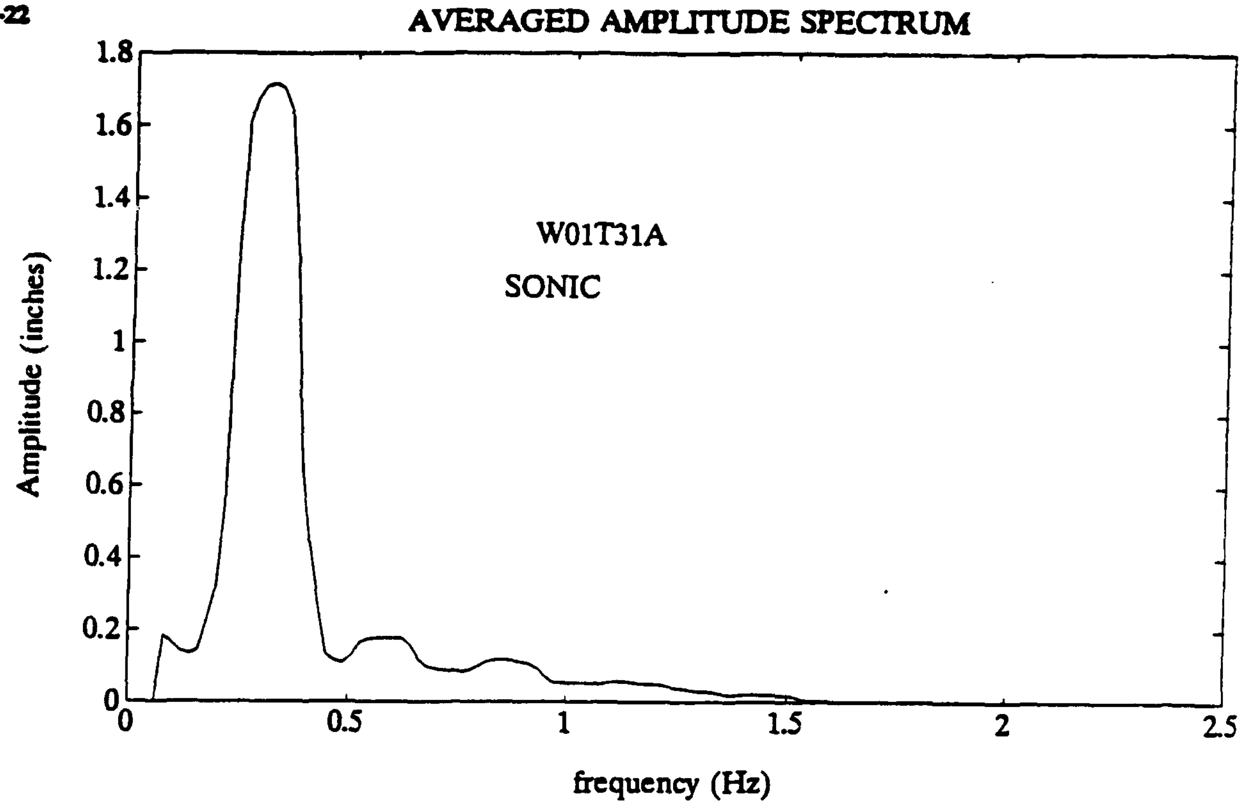


Figure B-14. Wave Averaged Amplitude Spectrum - W01T17A & W01T17B

Table B-8. NOFI 600S OILBOOM WAVE DATA

FILE/TEST #	AVERAGE H 1/3 (inches)	PRE-TEST H 1/3 (inches)	POST TEST H1/3 (inches)	AVE APPARENT PERIOD (seconds)	PRE-TEST A.A.P. (seconds)	POST TEST A.A.P. (seconds)
W01T31A	9.15	7.47	9.59	3.7	3.67	3.71
W01T31B	5.66	5.62	5.26	4.64	4.44	4.87
W01T34A	12.73	13.91	11.44	1.85	1.89	1.8
W01T34B	16.77	17.71	15.48	2.4	2.39	2.39
W01T41A	7.34	7.7	5.96	4.46	4.42	4.42
W01T41B	8.55	8.87	6.29	4.6	4.64	4.57
W01T44A	18.41	20.33	14.56	2.26	2.16	2.26
W01T44B	20.2	14.82	21.78	2.38	2.43	2.3



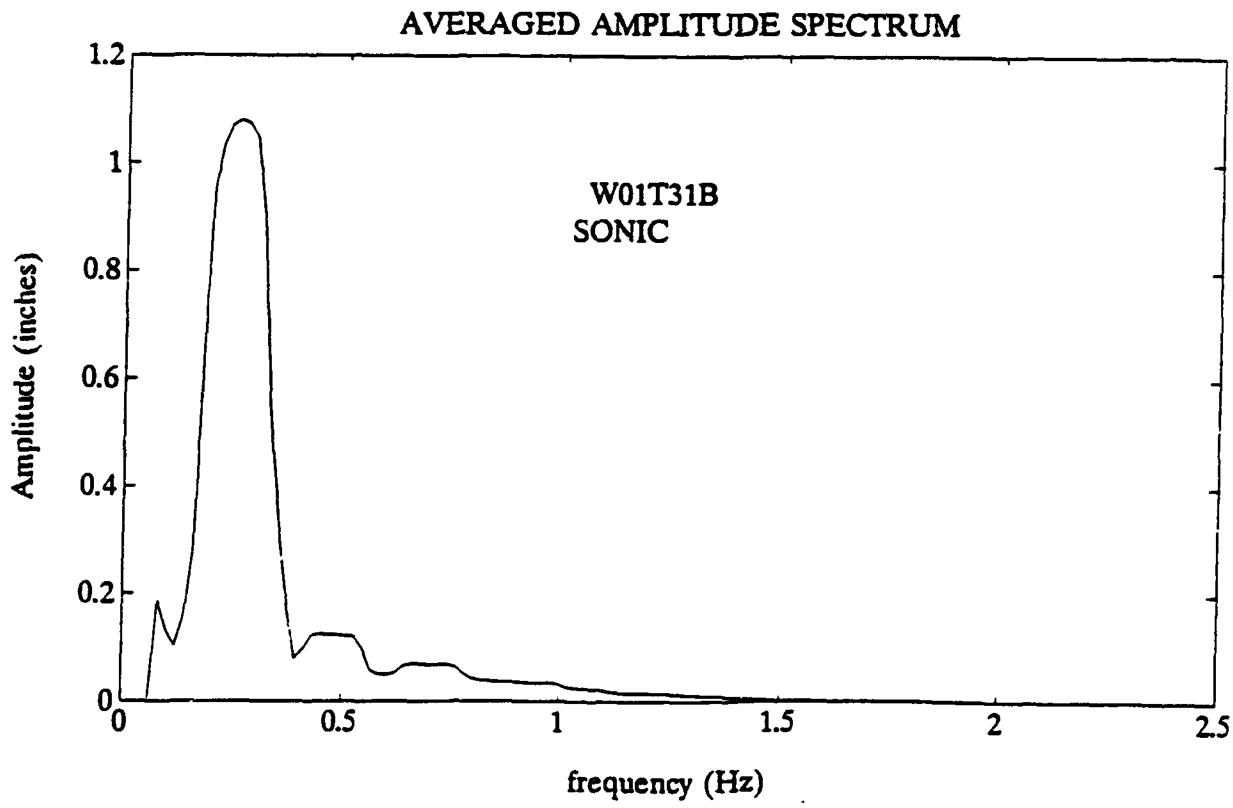
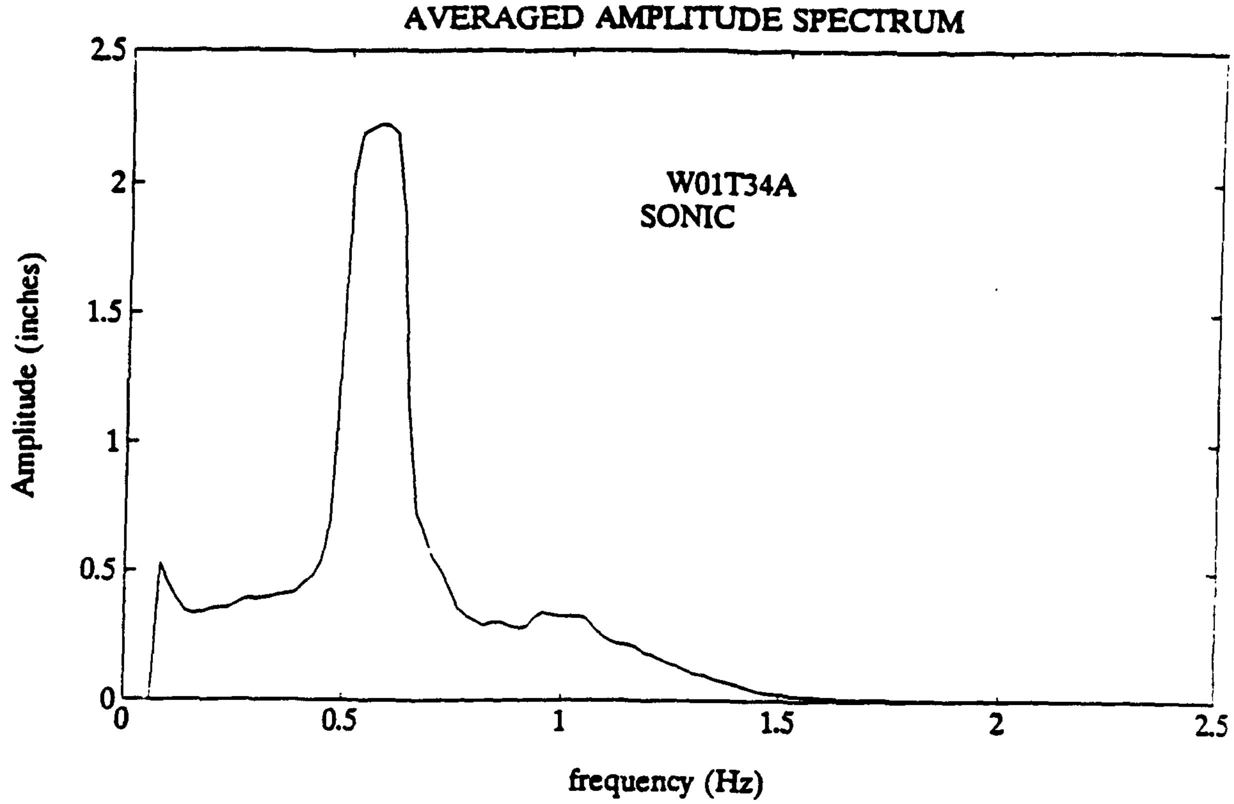


Figure B-15. Wave Averaged Amplitude Spectrum - W01T31A & W01T31B



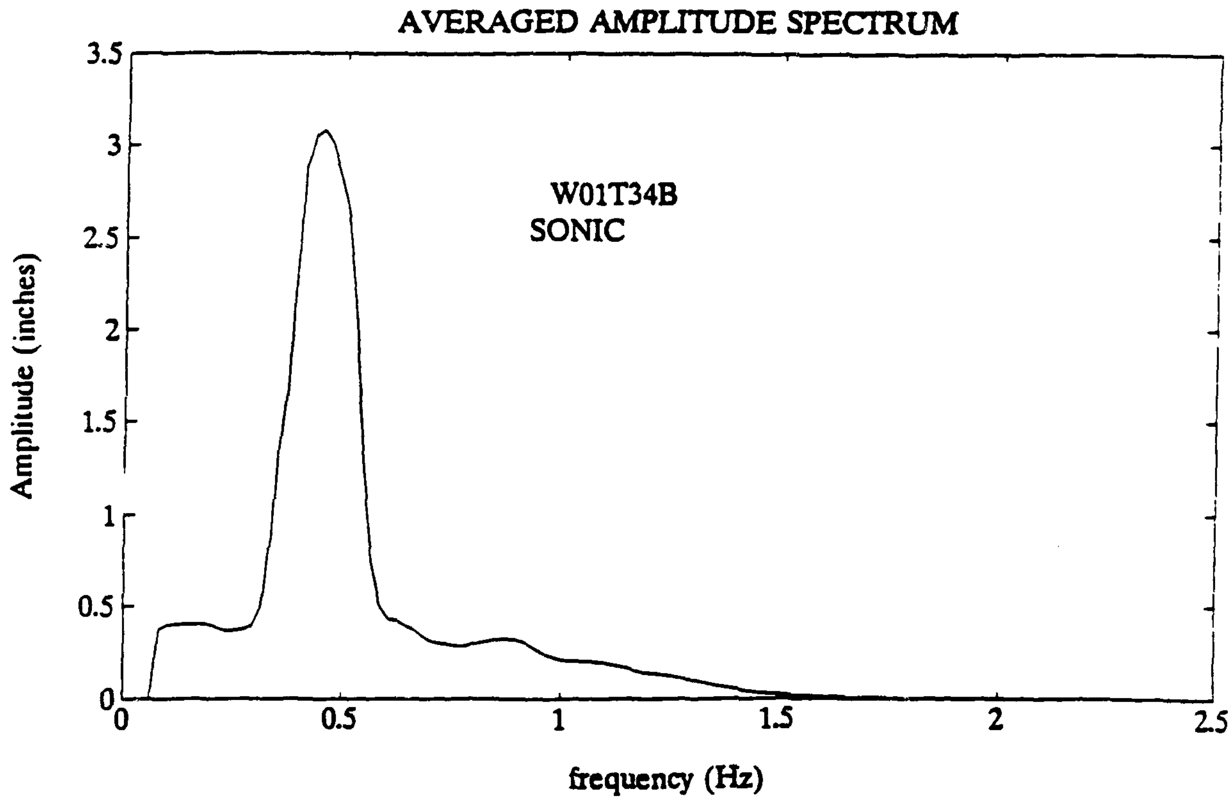
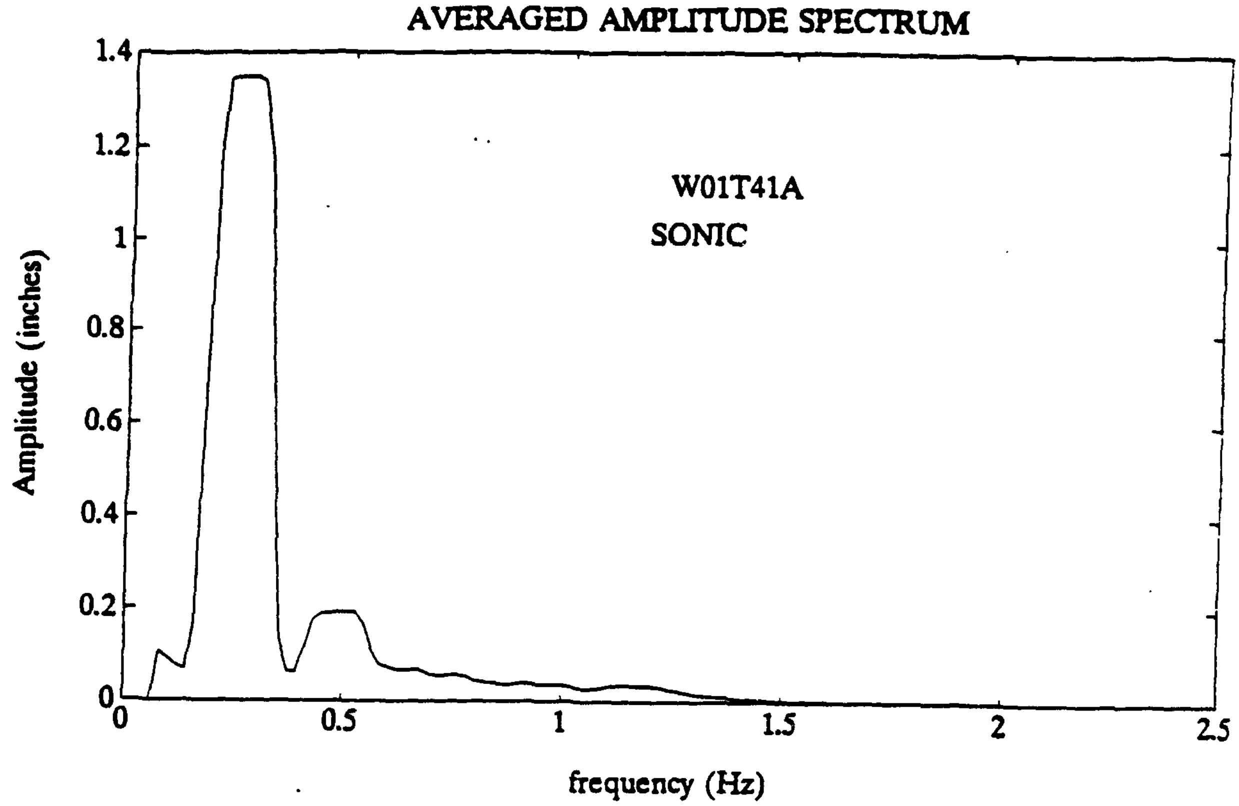


Figure B-16. Wave Averaged Amplitude Spectrum - W01T34A & W01T34B



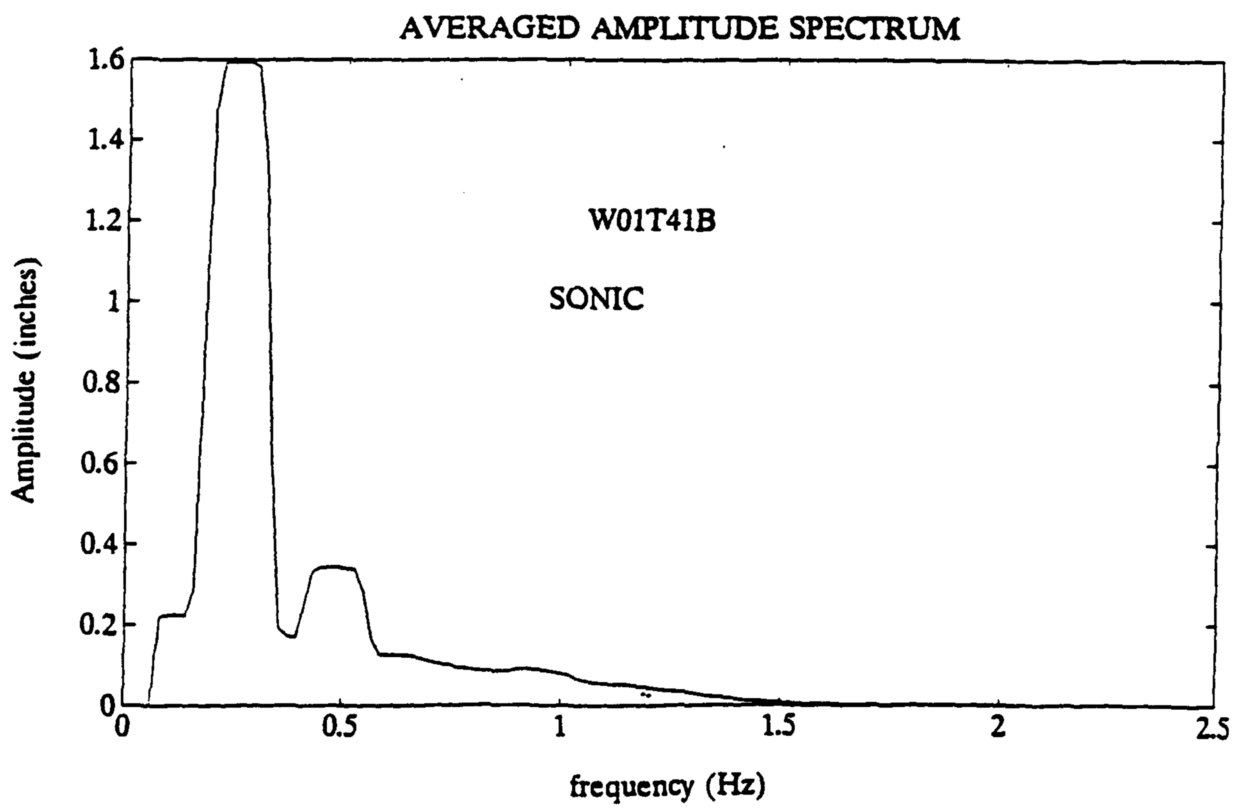
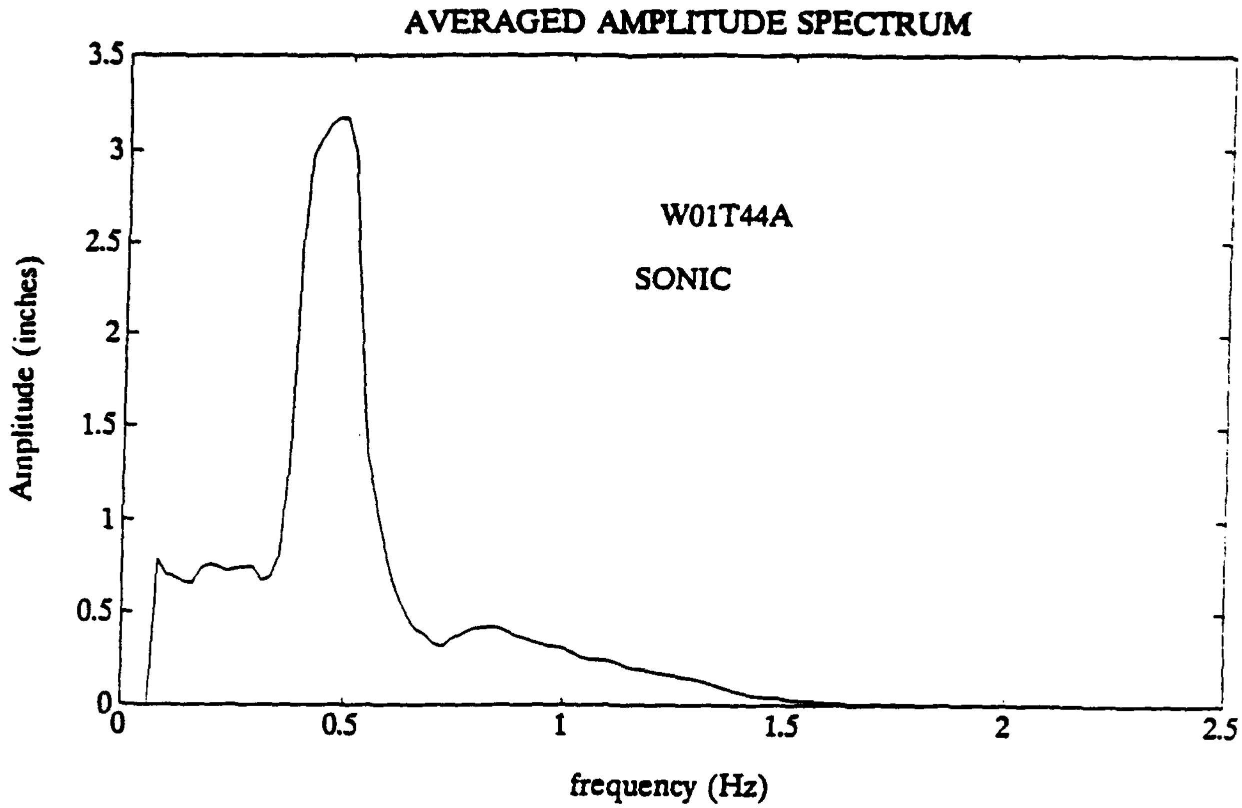


Figure B-17. Wave Averaged Amplitude Spectrum - W01T41A & W01T41B



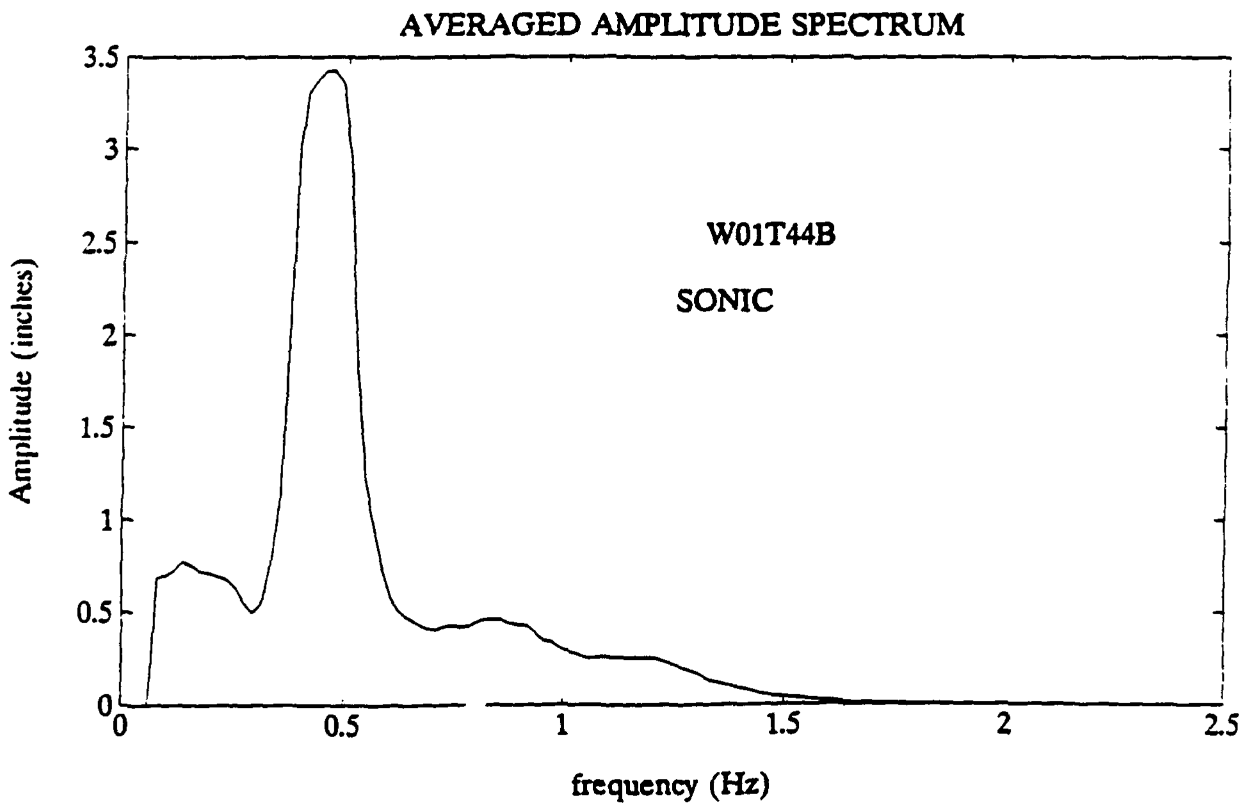
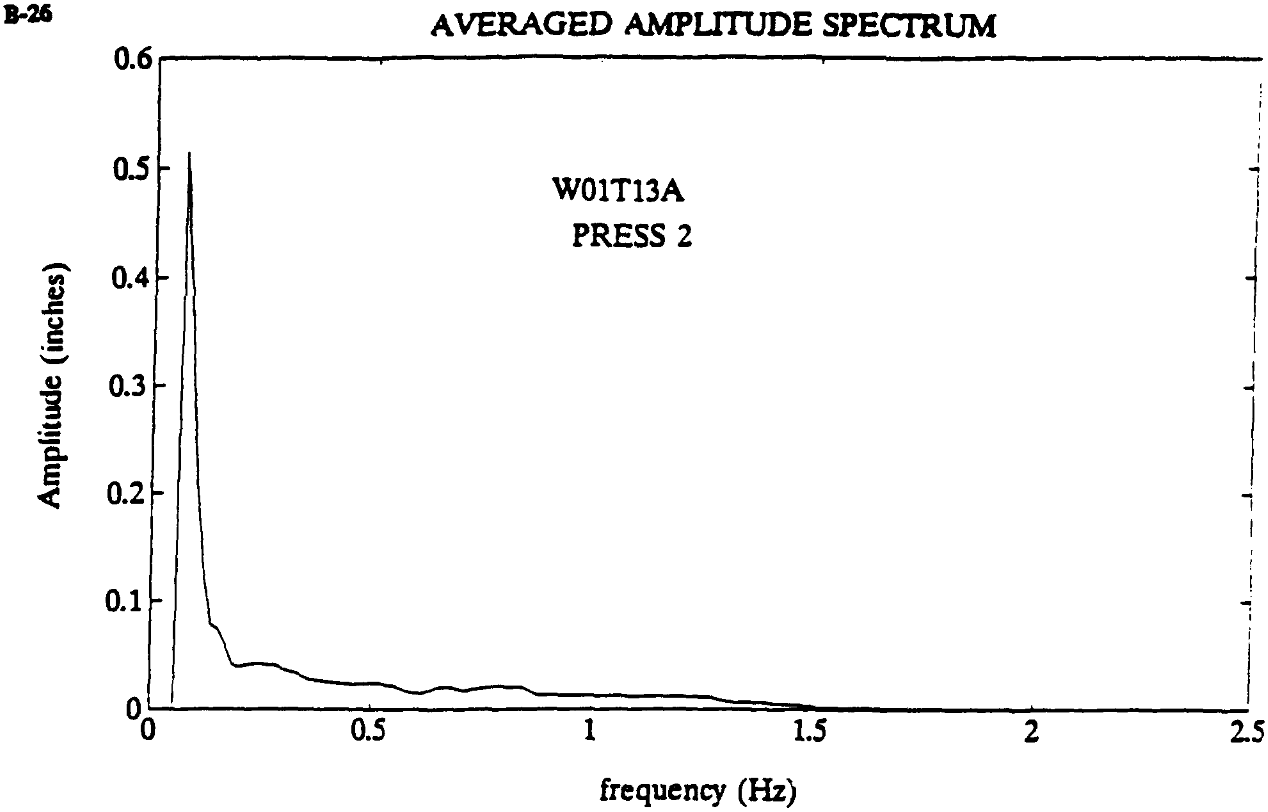


Figure B-19. Wave Averaged Amplitude Spectrum - W01T44A & W01T44B



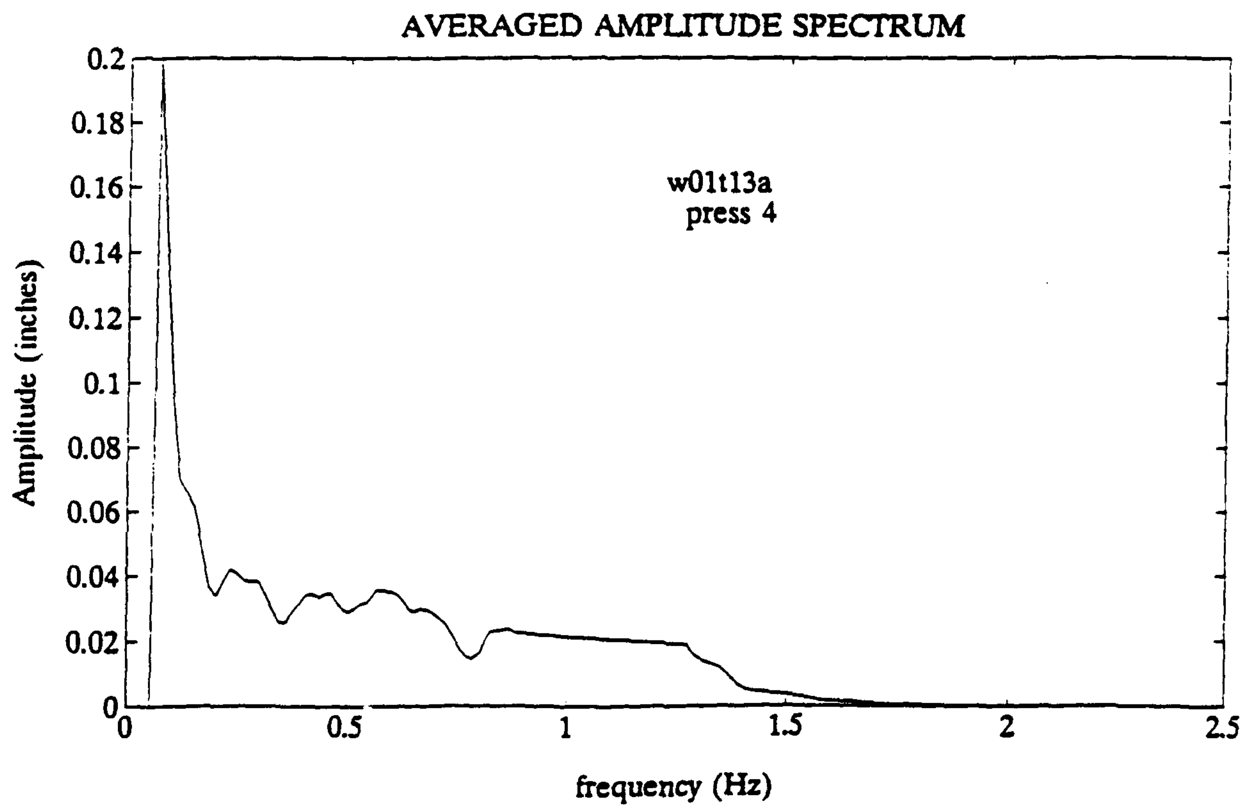


Figure B-19. Wave Averaged Amplitude Spectrum - W01T13A (Press 2&4)

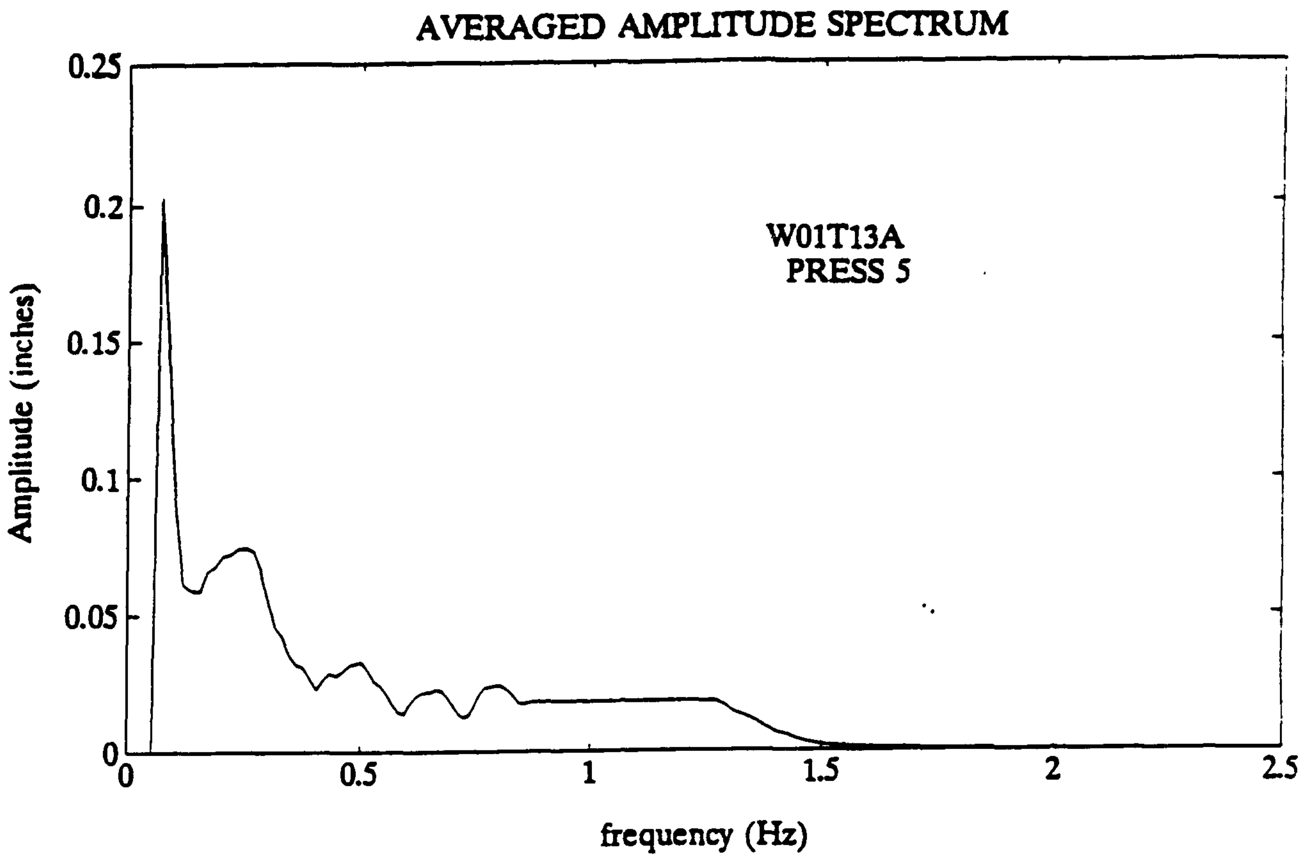
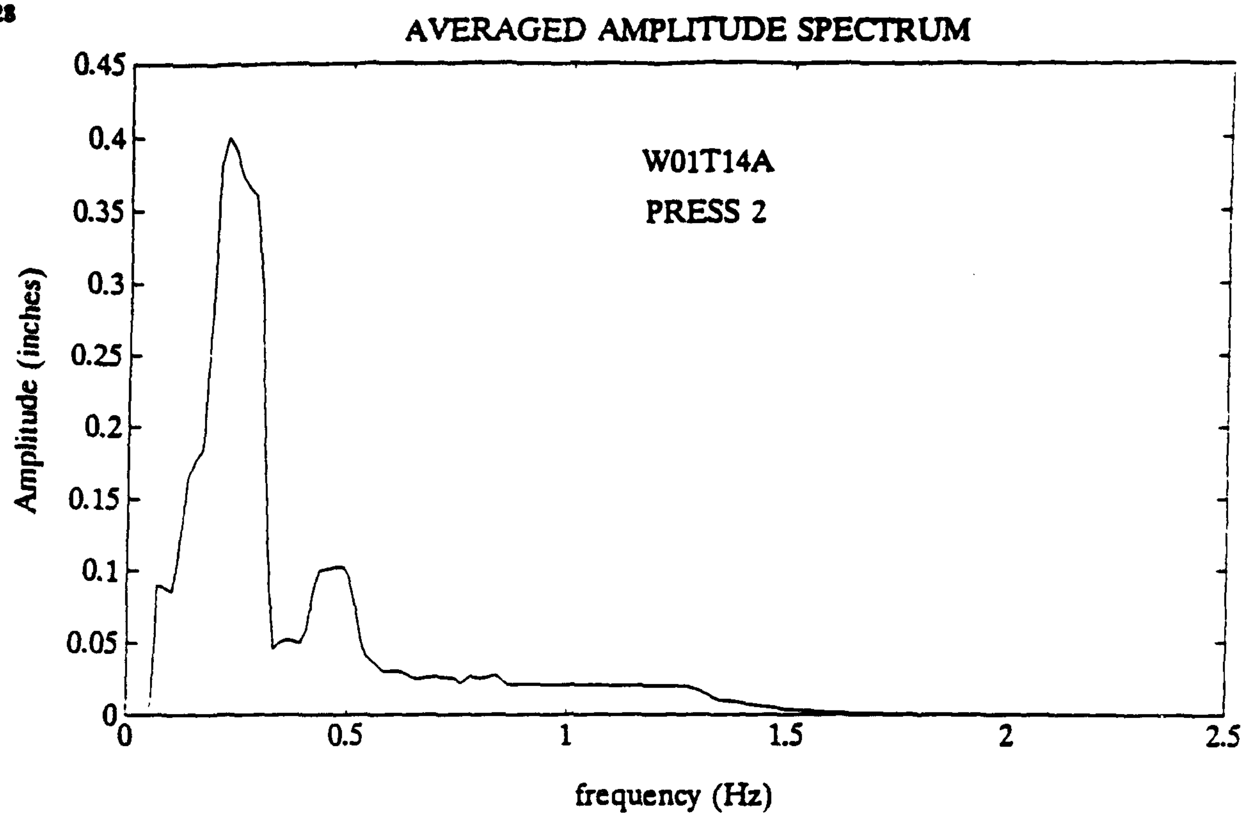


Figure B-20. Wave Averaged Amplitude Spectrum - W01T13A (Press 5)



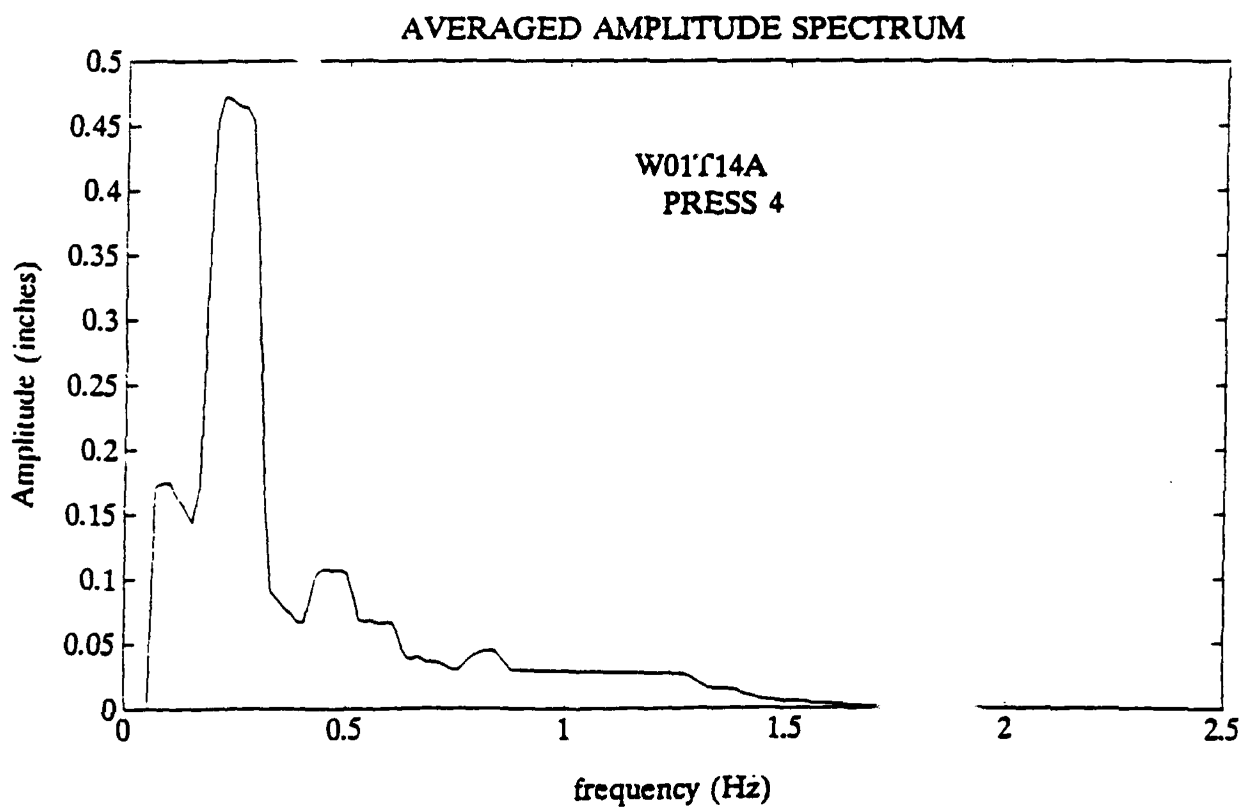


Figure B-21. Wave Averaged Amplitude Spectrum - W01T14A (Press 2&4)

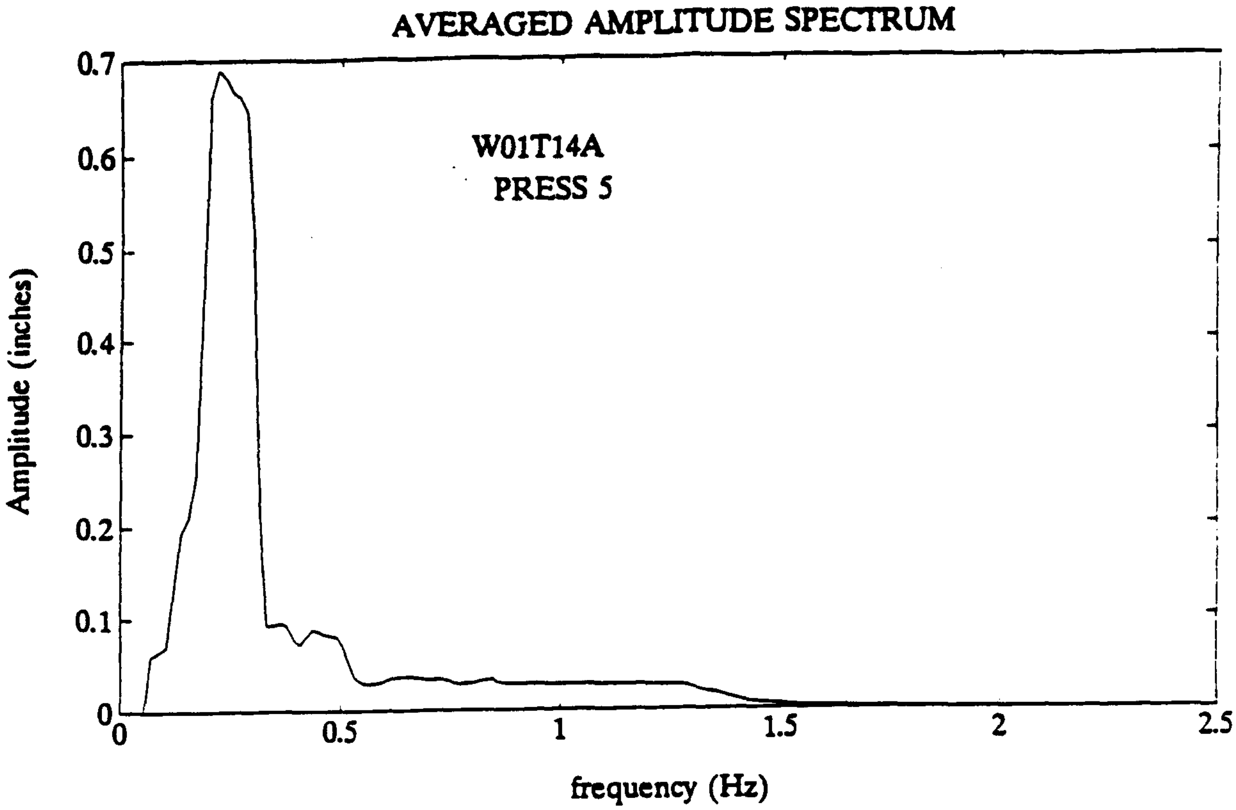
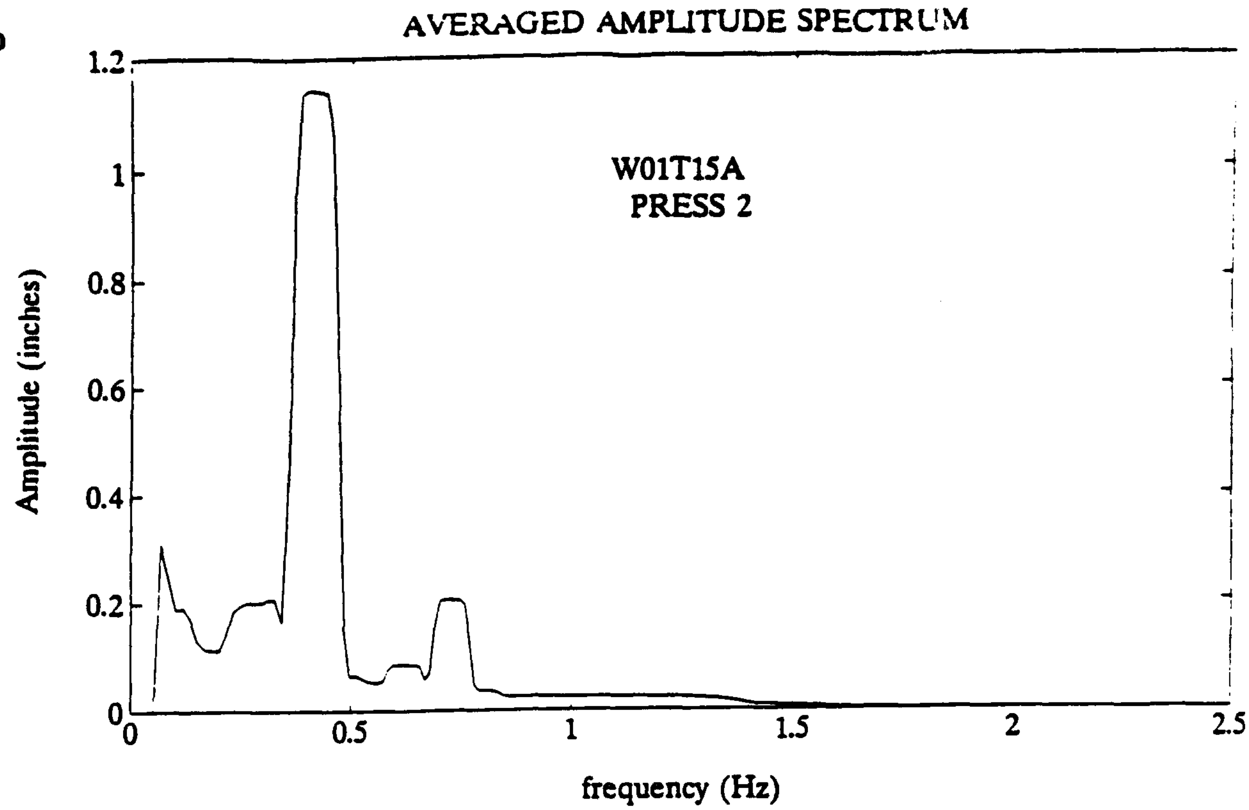


Figure B-22. Wave Averaged Amplitude Spectrum - W01T14A (Press 5)



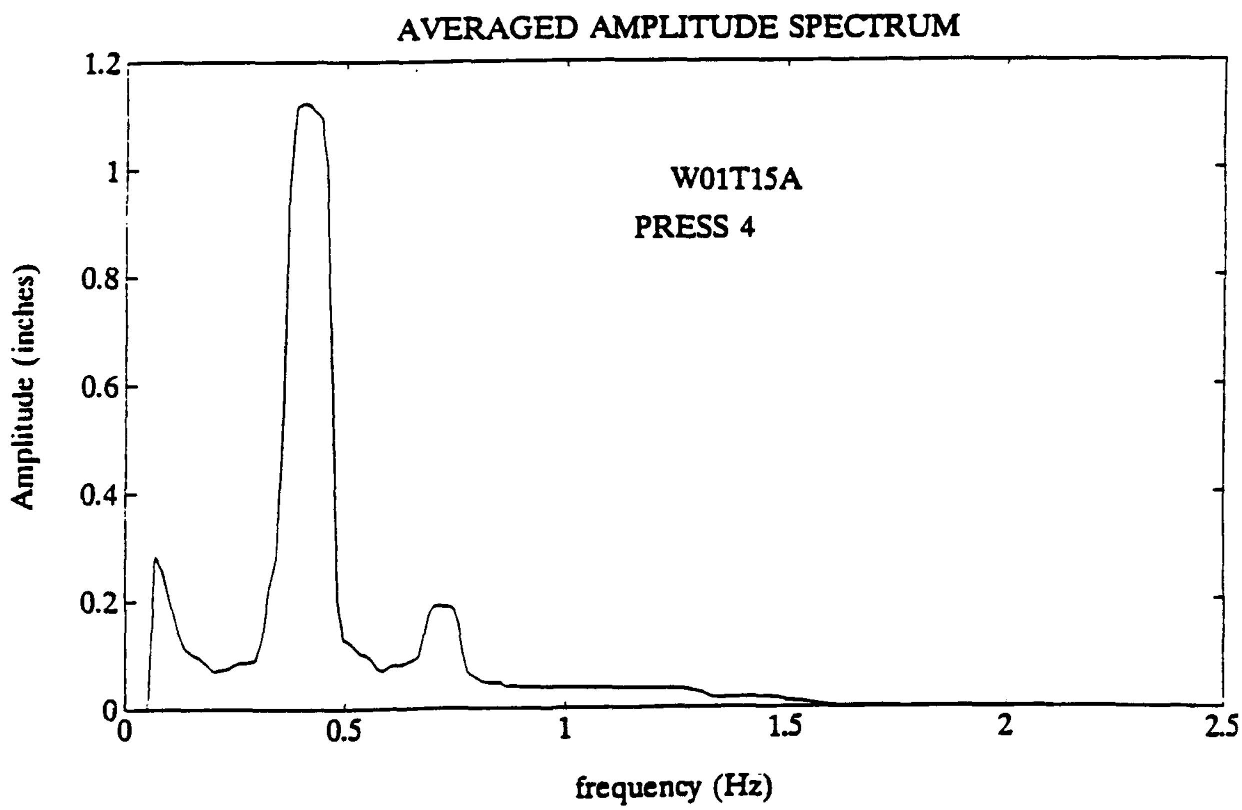


Figure B-23. Wave Averaged Amplitude Spectrum - W01T15A (Press 2&4)

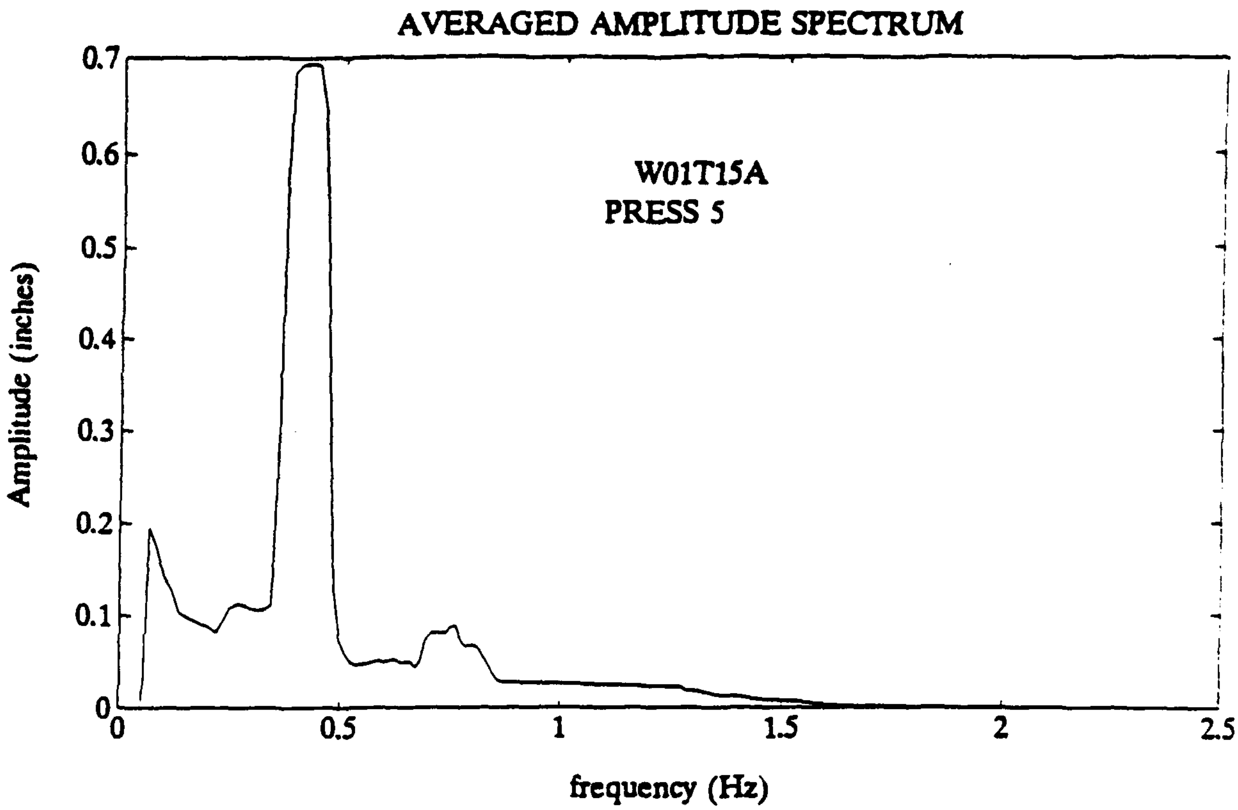
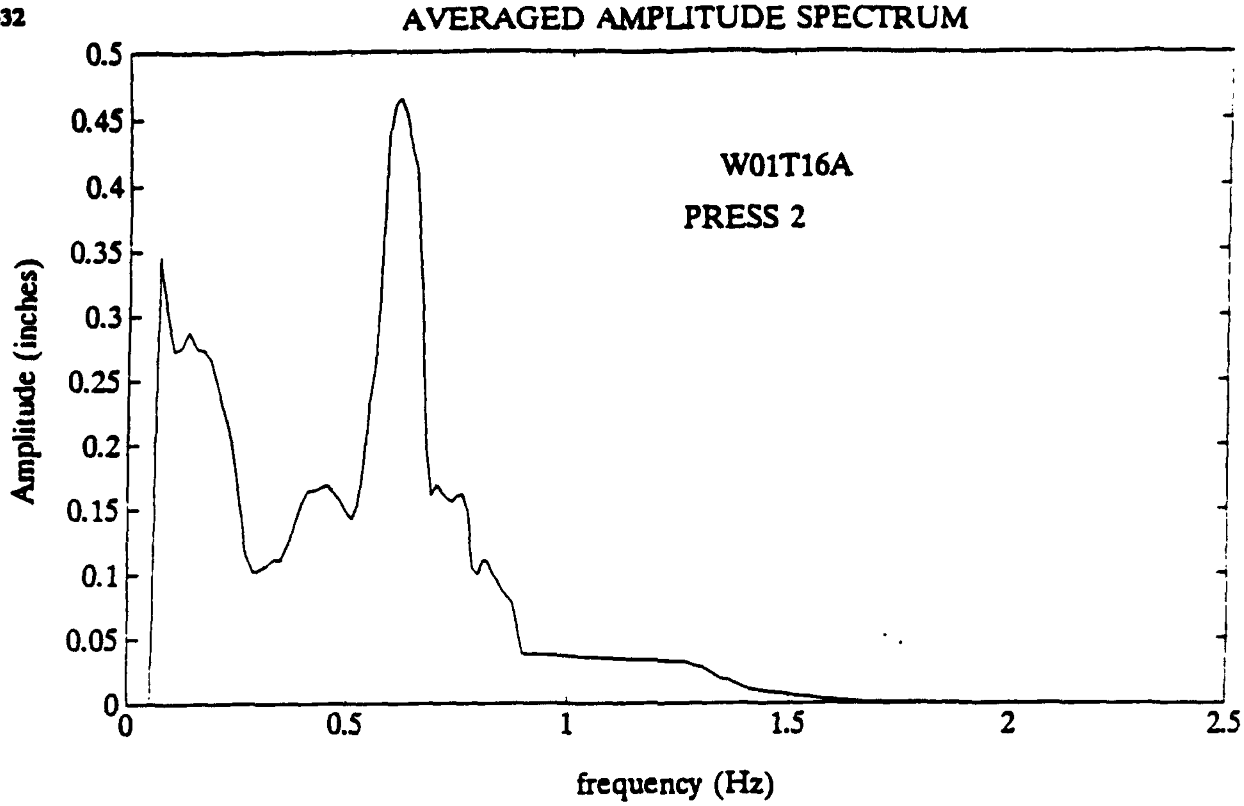


Figure B-24. Wave Averaged Amplitude Spectrum - W01T15A (Press 5)



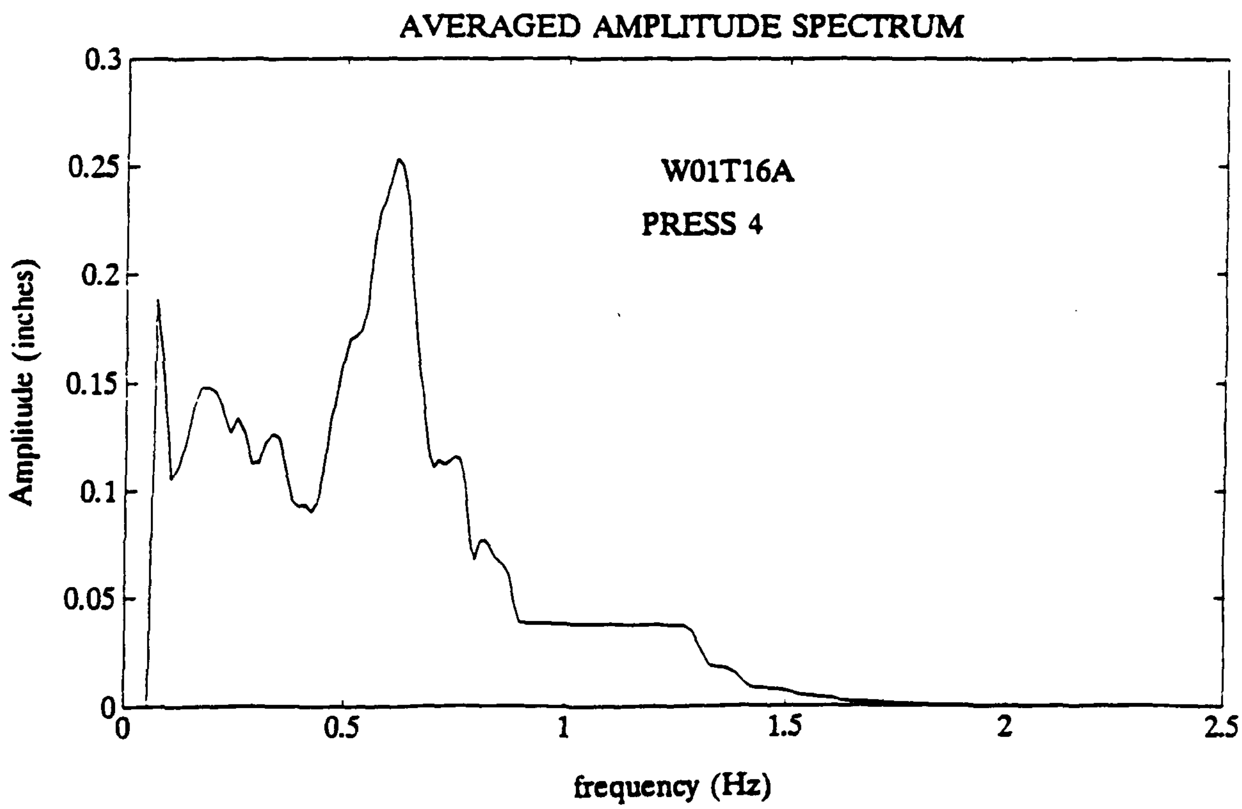


Figure B-25. Wave Averaged Amplitude Spectrum - W01T16A (Press 2&4)

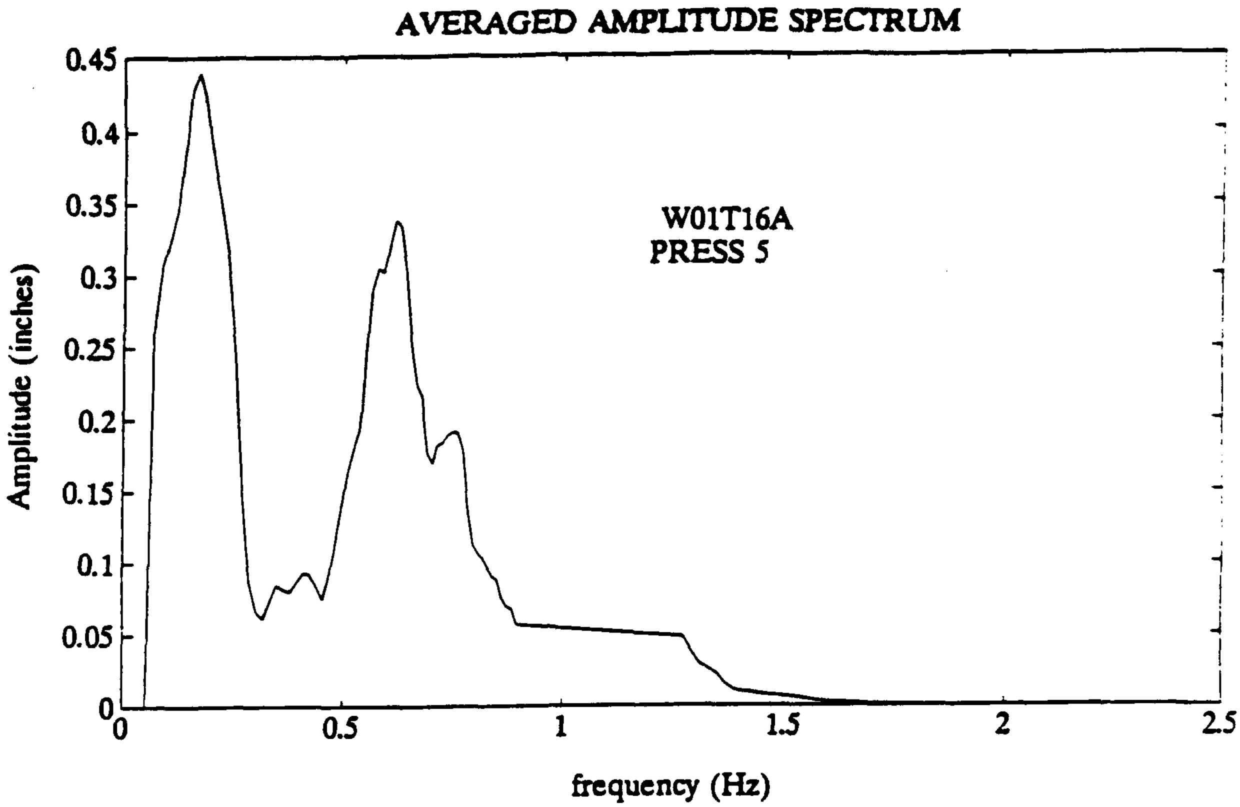
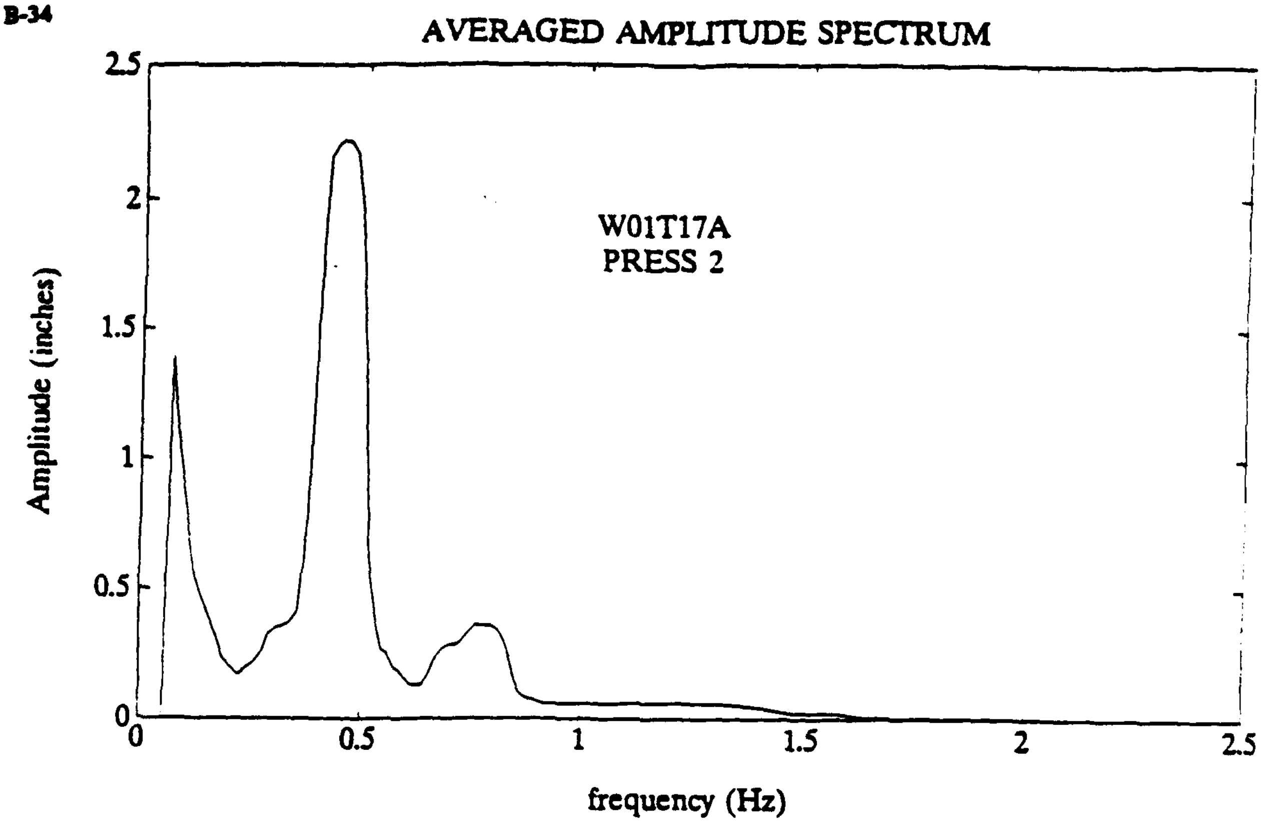


Figure B-26. Wave Averaged Amplitude Spectrum - W01T16A (Press 5)



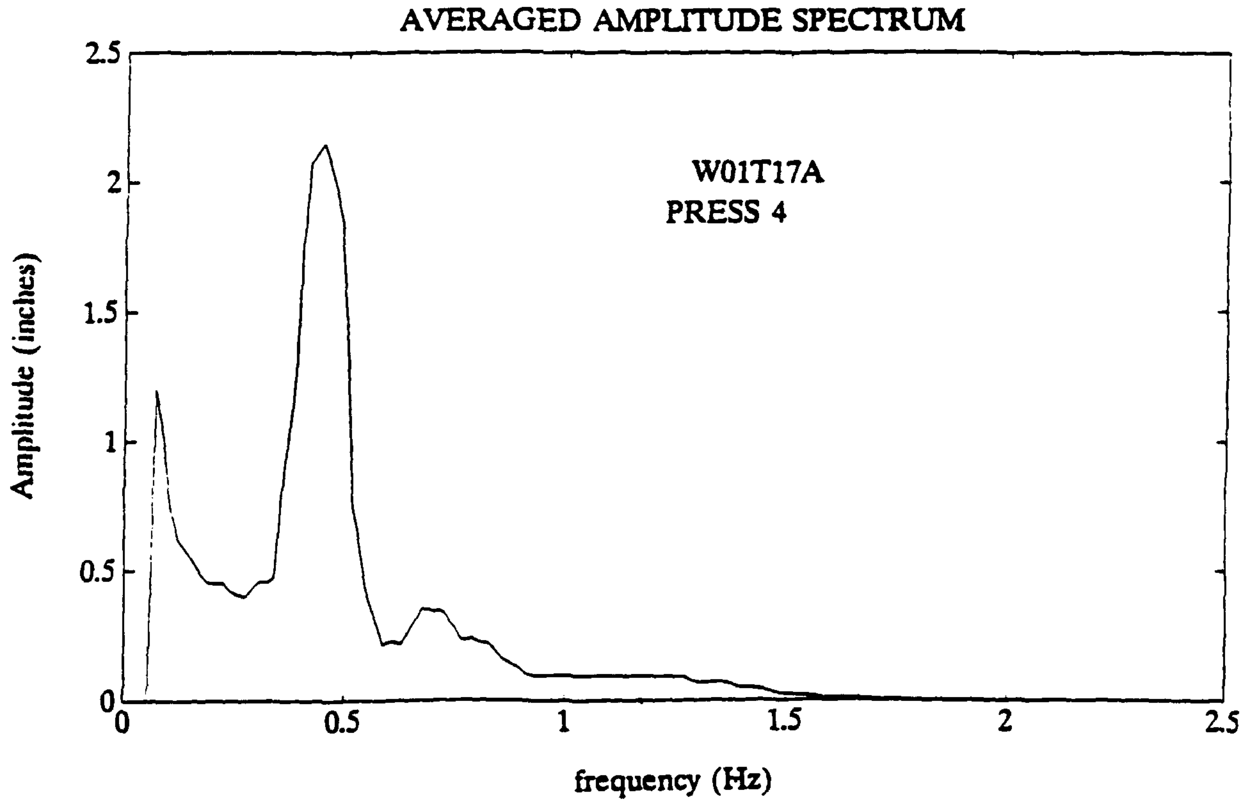


Figure B-27. Wave Averaged Amplitude Spectrum - W01T17A (Press 2&4)

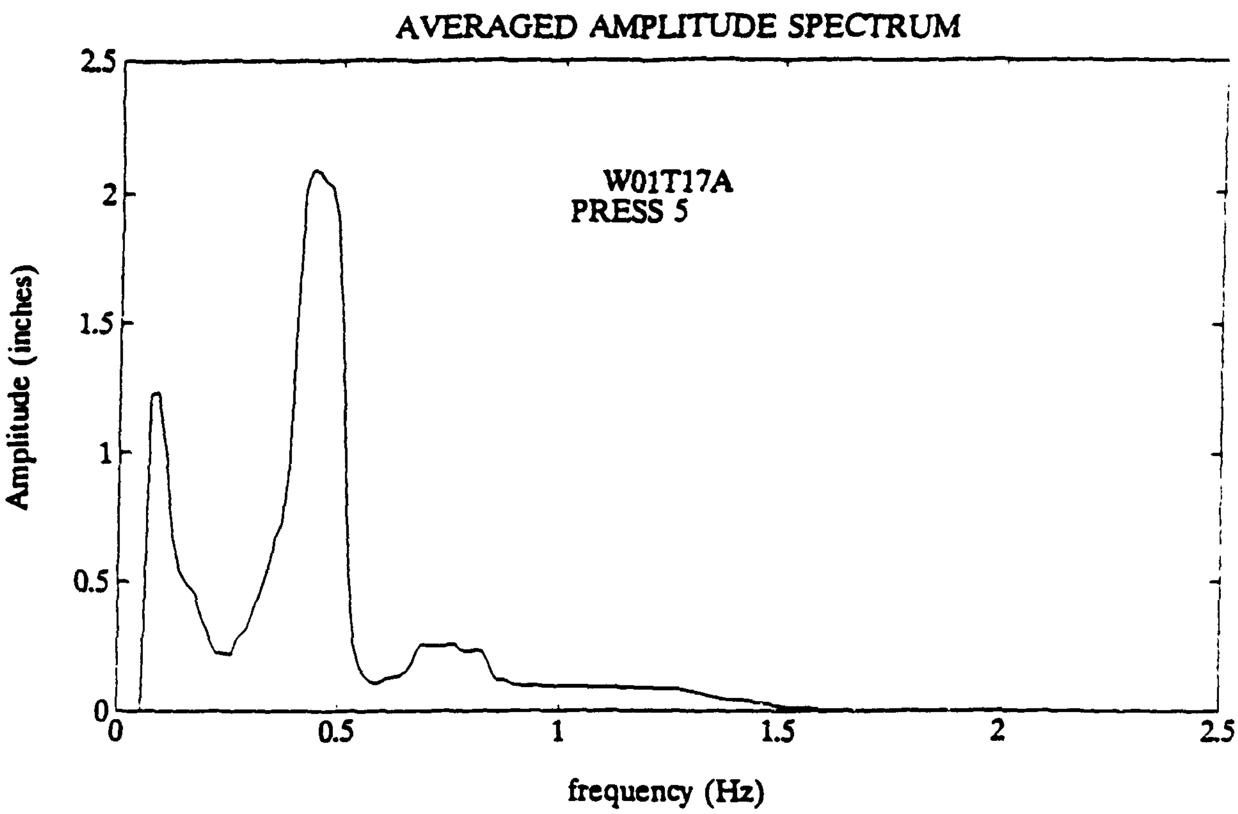
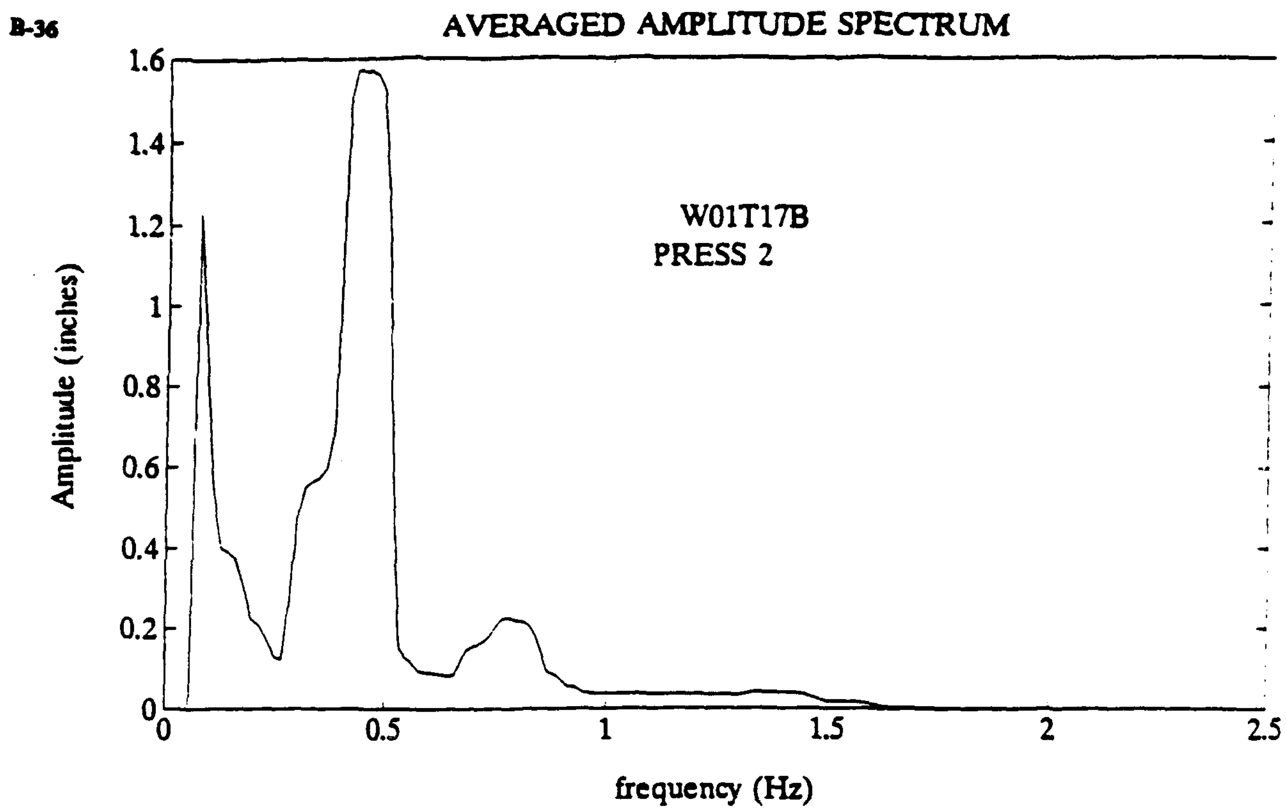


Figure B-28. Wave Averaged Amplitude Spectrum - W01T17A (Press 2&4)



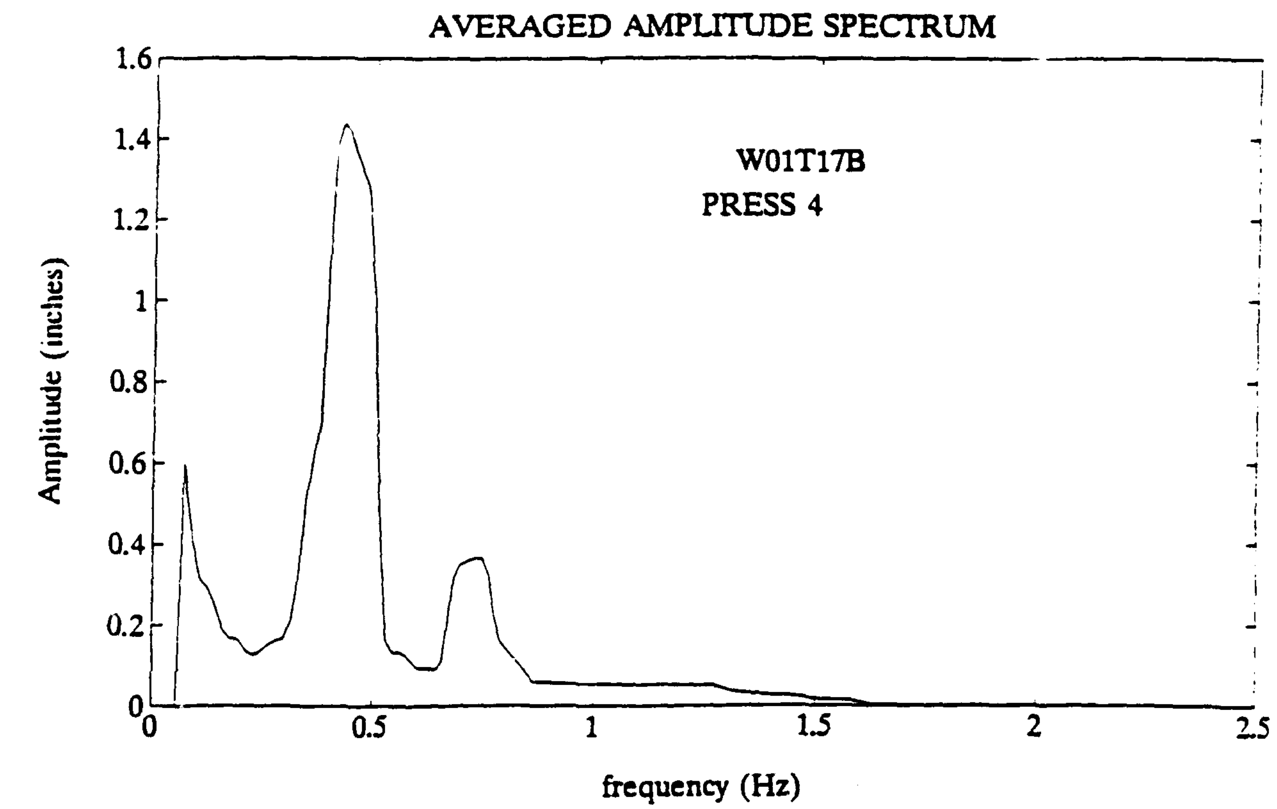


Figure B-29. Wave Averaged Amplitude Spectrum - W01T17B (Press 2&4)

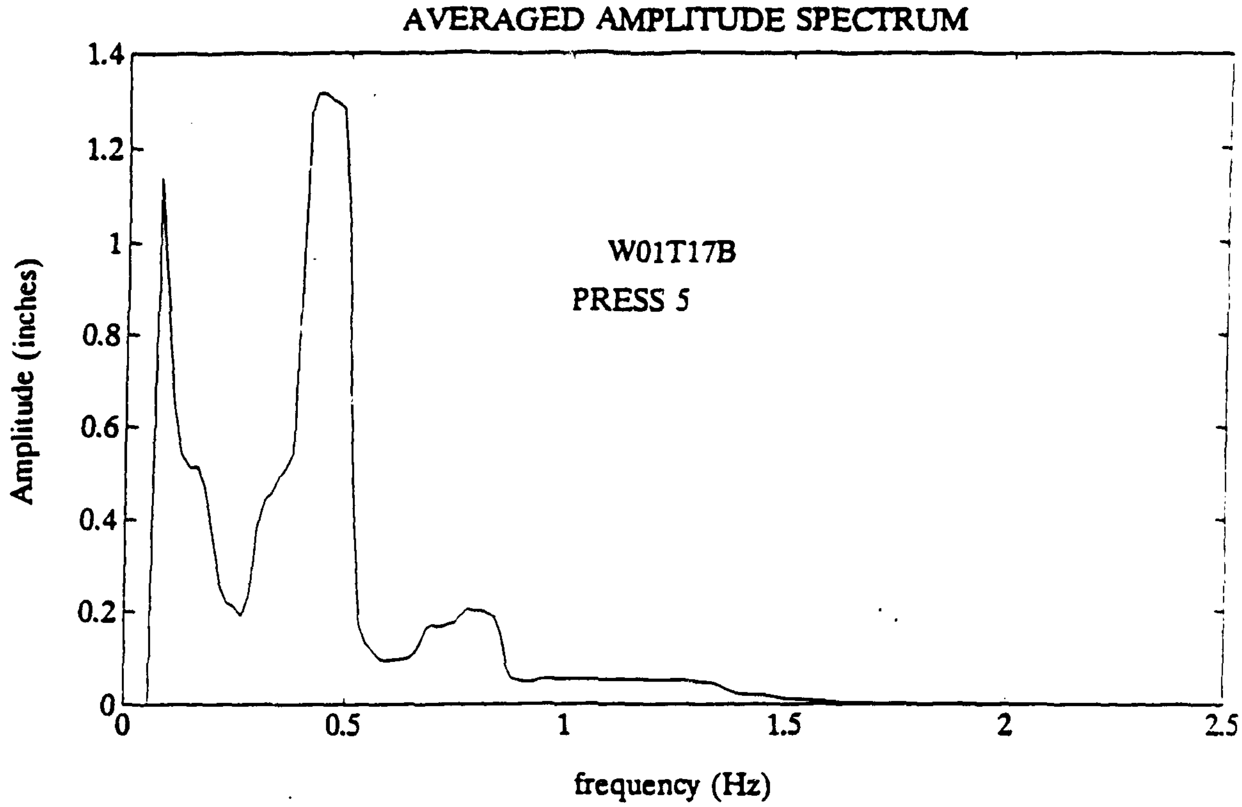


Figure B-30. Wave Averaged Amplitude Spectrum - W01T17B (Press 5)

Accuracy of Spectral Plots

The spectral plots shown in this report result from averaging the individual spectra for a number of individual 512 point (51.2 second) segments of time-series data. For most data sets, 210 seconds (four segments) of wave data is taken both pre-test and post-test. The resulting averaged spectra are the average for the eight segments. The spectra presented in the plots represent wave amplitude in inches at given frequencies.

The standard deviation of the actual amplitude at a given frequency on a spectral plot is:

$$\sigma = \frac{A}{\sqrt{n}}$$

where: A is the actual (not the calculated) amplitude
n is the number of averages which were used in computing the spectrum.

There are two averaging methods used. The first averaging technique is "ensemble-averaging", in which the amplitude at each frequency is the average of the amplitudes at that frequency for k individual data segments, the spectra of which have been computed independently. This technique increases the level of confidence in the amplitudes at each frequency.

The second averaging technique is "frequency averaging", which applies a moving-average filter to the ensemble-averaged amplitudes. In this technique, each individual amplitude value is replaced by the average of the value itself and the amplitudes for the k nearest frequencies above and below. This technique increases the level of confidence in the amplitudes at the expense of a loss of frequency resolution.

Thus, for the averaged spectral plots, the total number of independent averages is $m(2k+1)$. For the plots shown in this report, $k=3$, resulting in 56 averages when eight 51.2 second segments of wave data are averaged.

We can be 68.4% confident that the calculated value of the amplitude for a given frequency will fall within one standard deviation of the actual value, and 95.4% confident that the calculated amplitude will fall within two standard deviations of the actual value. (Note that the standard deviation here is expressed as a fraction of the actual value, rather than as a fixed number).

Applying these criteria, the actual value of the amplitude is within the range from $1/(1+\sigma)$ to $1/(1-\sigma)$ times the calculated amplitude with 68% confidence, and within the range from $1/(1+2\sigma)$ to $1/(1+2\sigma)$ times the calculated amplitude with 95% confidence.

At the 68% confidence level, the calculated value should be no lower than $(1-\sigma)$ times the actual value and no higher than $(1+\sigma)$ times the actual value. Rearranging these statements, the highest likely actual value (at the 68% confidence level) should be no higher than $1/(1-\sigma)$ times the calculated value and the lowest likely actual value should be no lower than $1/(1+\sigma)$ times the calculated value.

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APPENDIX C

OIL TESTING

(Lists of Tables and Figures are on Page C-12)

TEST METHODS

The measurements made in the chemical laboratory at the Ohmsett Facility are as follows:

1. VISCOSITY (ASTM D341)

Viscosity is measured using a Brookfield Engineering Model LV Viscometer. The samples are collected in 600 ml beakers, the contents are cooled to 10° C then the temperature is raised to 60° C using a Brookfield Constant Temperature Bath. Viscosity measurements are made every 5-10°, yielding a temperature vs. viscosity curve for each sample obtained. This is done to find the viscosity at variable test temperatures as is found in the test tank.

2. SURFACE & INTERFACIAL TENSION (ASTM D971)

Surface and interfacial tensions are measured with a Fisher Scientific Tensiomat. Approximately 50 mls of oil is needed to determine both surface and interfacial tensions. Measurements are made under standardized nonequilibrium conditions in which the measurement is completed 1 minute after formation of the interface.

3. SPECIFIC GRAVITY (ASTM D1298)

This analysis is performed usig the hydrometer method. The oil sample is transferred to a 500 ml cylinder, the appropriate hydrometer is lowered into the sample and allowed to settle. The hydrometer scale is read and the temperature is recorded.

4. WATER AND SEDIMENT IN PETROLEUM (ASTM D1796)

A recovered oil sample of approximately 100 mls is mixed with an appropriate solvent (toluene), heated, and rotated at 2000 rpm in a centrifuge for 10 minutes. The amount of water and sediment is measured and the percentages calculated from the amount of sample used.

SAMPLING PROCEDURES

Physical characteristics of the test oils (viscosity vs. temperature, specific gravity, surface and interfacial tensions) were analyzed once a day on days that oil was spilled into the test tank. These samples are noted as W01-1 for the first day of testing, W01-2 for the second, etc. A second set of analyses were performed if oil was transferred to the bridge storage tank from the tank farm and more tests were run during that day. These samples are recorded as W01-5A, W01-6A, etc. The oil samples were taken from the distribution manifold on the main bridge.

Water and sediment in petroleum (bottom solids & water) analyses were done for every test that oil was spilled and recovered from the test tank and transferred into the recovery tanks on the auxillary bridge. The cell of the recovery tank from which the sample was taken is also recorded. The oil was extracted using a Johnson stratified sampling thief to get a representative oil/water mixture of the entire cell.

OIL ANALYSES DISCUSSION

Laboratory analyses of the test oils began on August 18, 1992 and were completed on October 6, 1992. There were a total of seven samples of Sundex 8600T and four samples of Hydrocal 300 taken for viscosity, surface and interfacial tension, and specific gravity. No duplicates of these samples were taken. Bottom solids and water measurements were done on 17 samples of Sundex 8600T, with no split samples run or duplicates taken.

The statistical parameters of the analyses are:

$$\text{Average (AVG)} = X_{avg} = \Sigma_1{}^n(X_i/n)$$

$$\text{Variance (VAR)} = s^2 = ((\Sigma_1{}^n(X_i-X_{avg})^2/n)$$

$$\text{Standard Deviation (STD DEV)} = s = ((\Sigma_1{}^n(X_i-X_{avg})^2/n).5$$

$$\text{Relative Std Deviation} = (\text{RSD\%}) = s/X_{avg}*100$$

Viscosity measurements of the Sundex 8600T oil gave an average viscosity of 16,286 centipoise at 25 degrees Celsius, with a relative standard deviation of 13%. The Hydrocal 300 oil gave an average of 248 centipoise at 25 degrees C, with a rsd of 31%. This high rsd could be due to the fact that the Hydrocal 300 was transferred into the same holding tanks that the Sundex 8600T had previously been in, and some residual Sundex appears to have mixed with the Hydrocal, giving slightly high to gradually lower viscosity readings as the bridge tank was repeatedly filled with Hydrocal.

Surface and interfacial tensions of the Sundex 8600T were 36.4 and 28.8 dynes/cm respectively at 25 degrees, with rsds of 0.9% and 0.5%. This oil was very difficult to work with, so measurements were done in a step-wise fashion starting at 20.0 dynes/cm and increased every 2 dynes/cm until the interface broke. Hydrocal 300 gave values of 32.0 and 20.8 dynes/cm with rsds of 1.4% and 3.4 % respectively. The precision of these values for both oils fall within the designated limits of the method.

The specific gravity at 25 degrees C of the Sundex 8600T was 0.960 with an rsd of 0.917%. Due to the adhesive property of this oil at 25 degrees, it was difficult to get consistent results. Hydrocal 300 had a specific gravity of 0.909 with an rsd of 0.569%.

Bottom solids and water analyses gave between 17% and 45% water, and between 0.1% and 2.0% solids in the recovered fluid taken from the auxillary bridge tanks. Sundex 8600T was the only oil used for these tests.

Table C-1. WO1 - NOFI BOOM
OIL CHARACTERISTICS

Oil Type	Sample (- Day#)	Date in Aug/Sep	Temp (C)	Specific Gravity	Viscosity (cPs)	ST (dynes/cm)	IFT (dynes/cm)
Sundex 8600T	WO1-1	18	25	0.945	18000	35.5	32.0
	-2	19	25	0.955	12000	35.0	28.0
	-3	20	25	0.968	15000	37.0	29.0
	-4	24	25	0.970	16000	38.0	29.0
	-5	25	25	0.955	17000	37.0	28.0
	-5A	25	25	0.958	18000	36.5	25.5
	-6	31	25	0.970	18000	36.0	30.0
	AVERAGE =			0.960	16286	36.4	28.8
	STD DEV =			0.009	2050	0.9	1.8
	VAR =			0.000	4.2E+06	0.9	3.4
	RSD =			0.917%	13%	2.6%	6.4%
Hydrocal 300	WO1-7	28	25	0.915	350	31.9	20.7
	-8	30	25	0.911	275	31.8	22.0
	-9	1	25	0.907	225	31.6	20.3
	-10	6	25	0.901	140	32.8	20.3
	AVERAGE =			0.909	248	32.0	20.8
	STD DEV =			0.005	76	0.5	0.7
	VAR =			0.000	5831	0.2	0.5
	RSD =			0.569%	31%	1.4%	3.4%

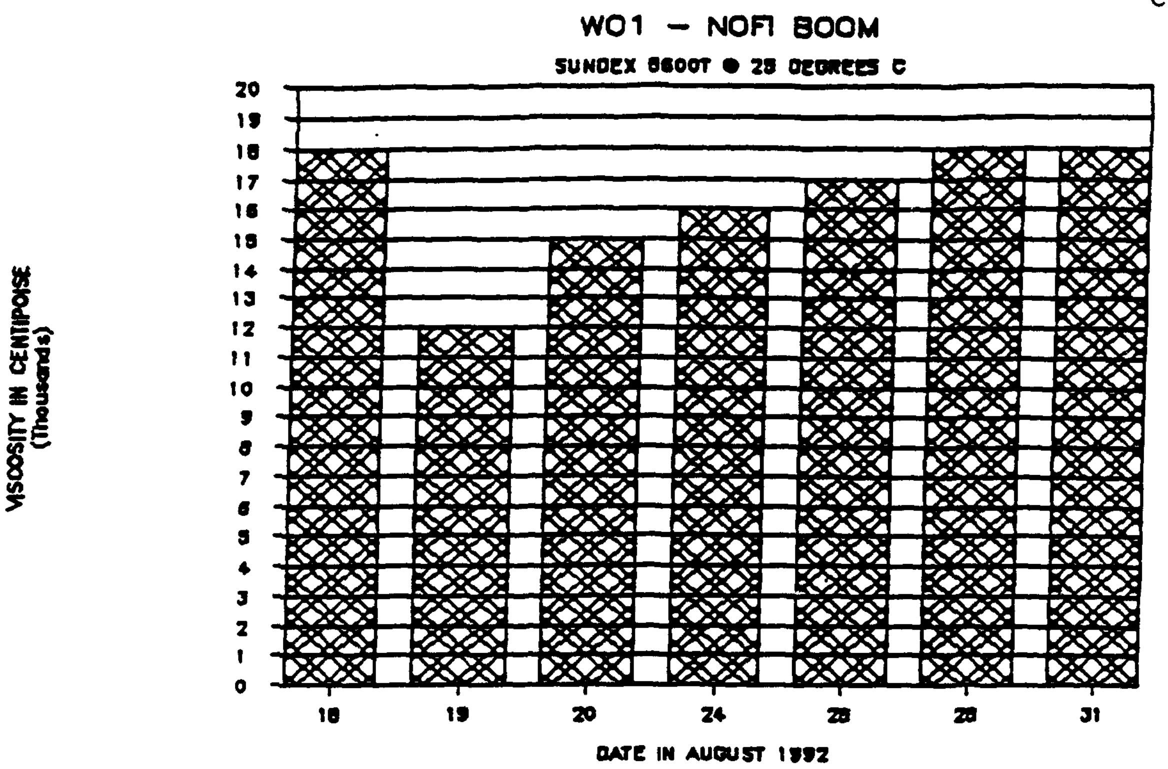


Figure C-1. Sundex 8600T Viscosity on Test Days

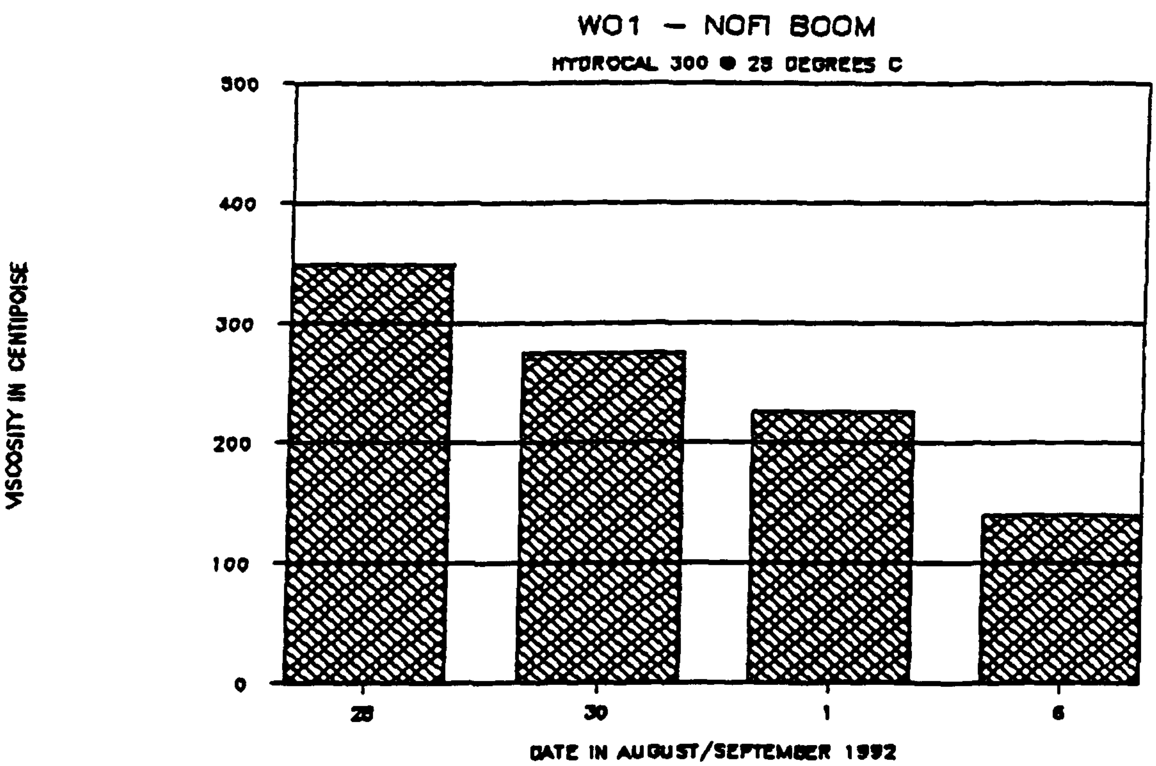


Figure C-2. Hydrocal 300 Viscosity on Test Days

Table C-2. **SUNDEX 8600T** - Temperature vs Viscosity Data

TEMP (C)	AVG VISC (cps)	LOG VISC	CALC LOG VISC
10	140000	5.146128	4.979911
15	72500	4.860338	4.724483
20	24250	4.384711	4.469054
25	16286	4.211814	4.213626
30	6215	3.793441	3.958197
40	2410	3.382017	3.447340
45	1625	3.210853	3.191912
50	592	2.772321	2.936483
55	337	2.527629	2.681055
60	300	2.477121	2.425626
70	150	2.176091	1.914769

Regression Output:WO1SUNLOG			Regression Output:WO1SUNCAL		
Constant		5.490769	Constant		5.490769
Std Err of Y Est		0.151438	Std Err of Y Est		0
R Squared		0.979940	R Squared		1
No. of Observations		11	No. of Observations		11
Degrees of Freedom		9	Degrees of Freedom		9
X Coefficient(s)	-0.05108		X Coefficient(s)	-0.05108	
Std Err of Coef.	0.002436		Std Err of Coef.	0	

Table C-3. HYDROCAL 300 - Temperature vs Viscosity Data

TEMP (C)	AVG VISC (cps)	LOG VISC	CALC LOG VISC
10	1625	3.210853	3.018580
15	515	2.711807	2.832004
20	364	2.561101	2.645428
25	248	2.394451	2.458852
30	186	2.269512	2.272276
35	125	2.096910	2.085700
40	87	1.939519	1.899124
45	55	1.740362	1.712548

Regression Output:WO1HYLOG			Regression Output:WO1HYCALC		
Constant		3.391733	Constant		3.391733
Std Err of Y Est		0.104254	Std Err of Y Est		0.000000
R Squared		0.957300	R Squared		1
No. of Observations		8	No. of Observations		8
Degrees of Freedom		6	Degrees of Freedom		6
X Coefficient(s)	-0.03731		X Coefficient(s)	-0.03731	
Std Err of Coef.	0.003217		Std Err of Coef.	0.000000	

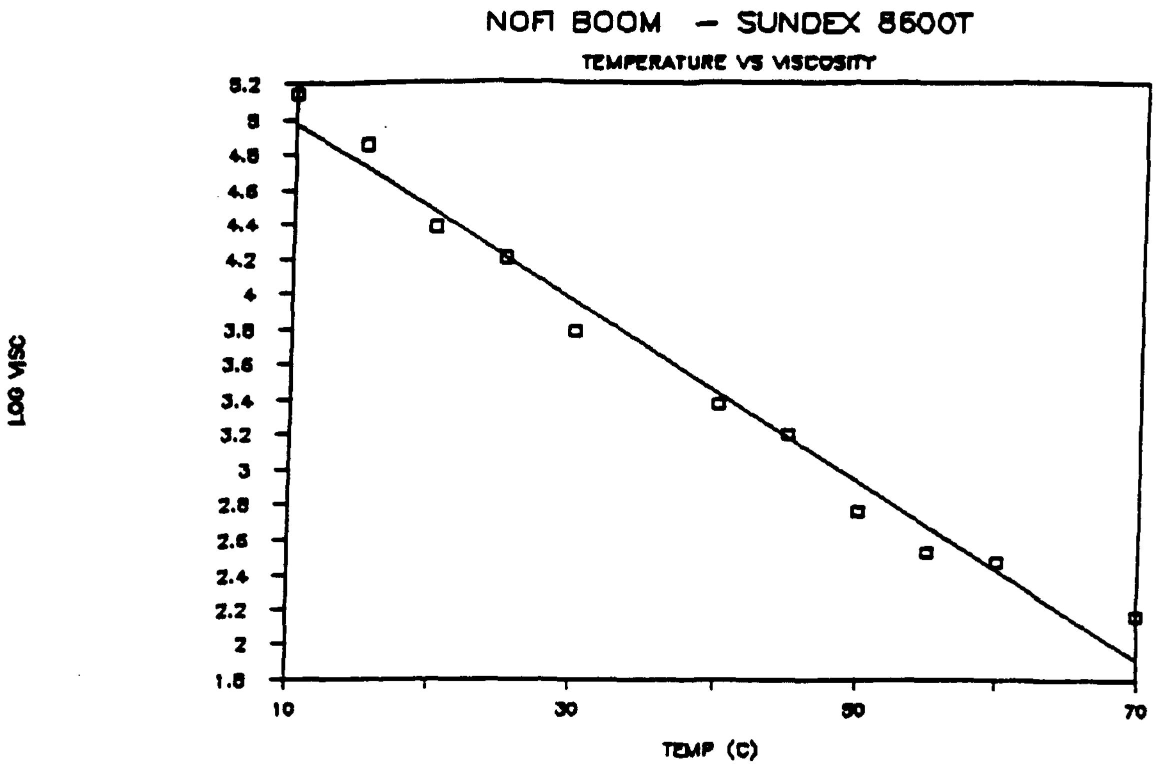


Figure C-3. SUNDEX 8600T Temperatures vs Viscosity Graph

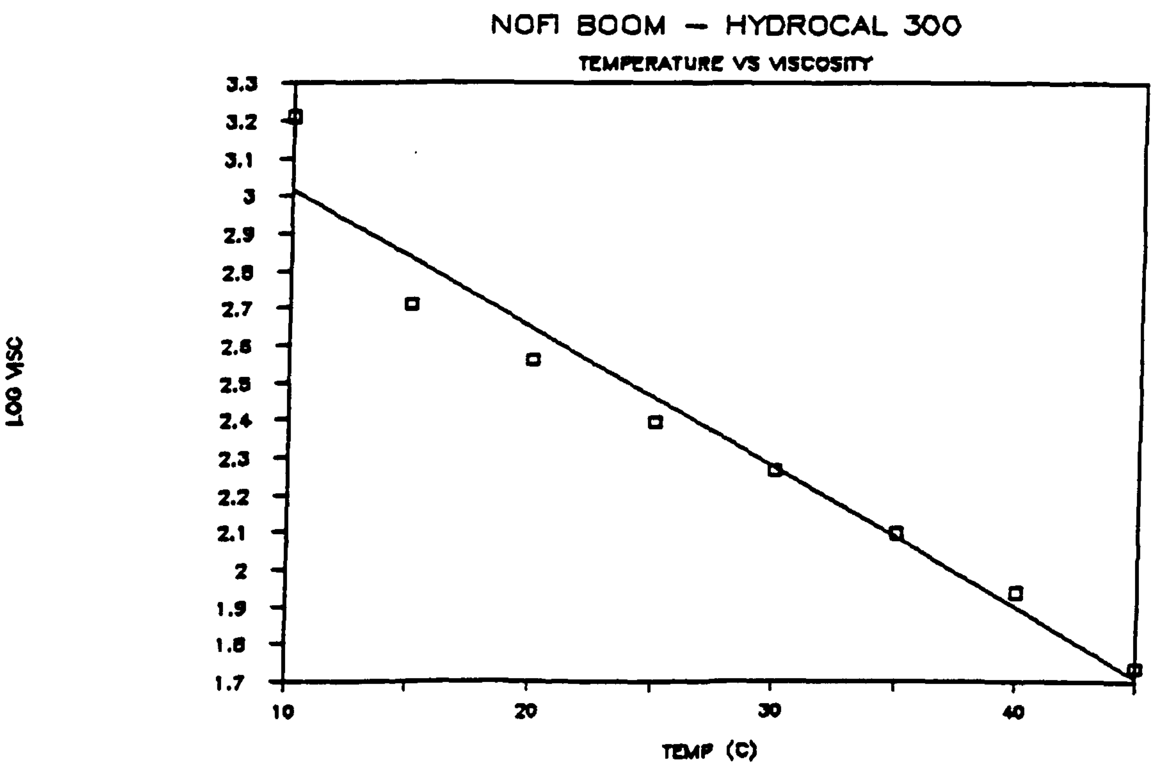


Figure C-4. HYDROCAL 300 Temperature vs Viscosity Graph

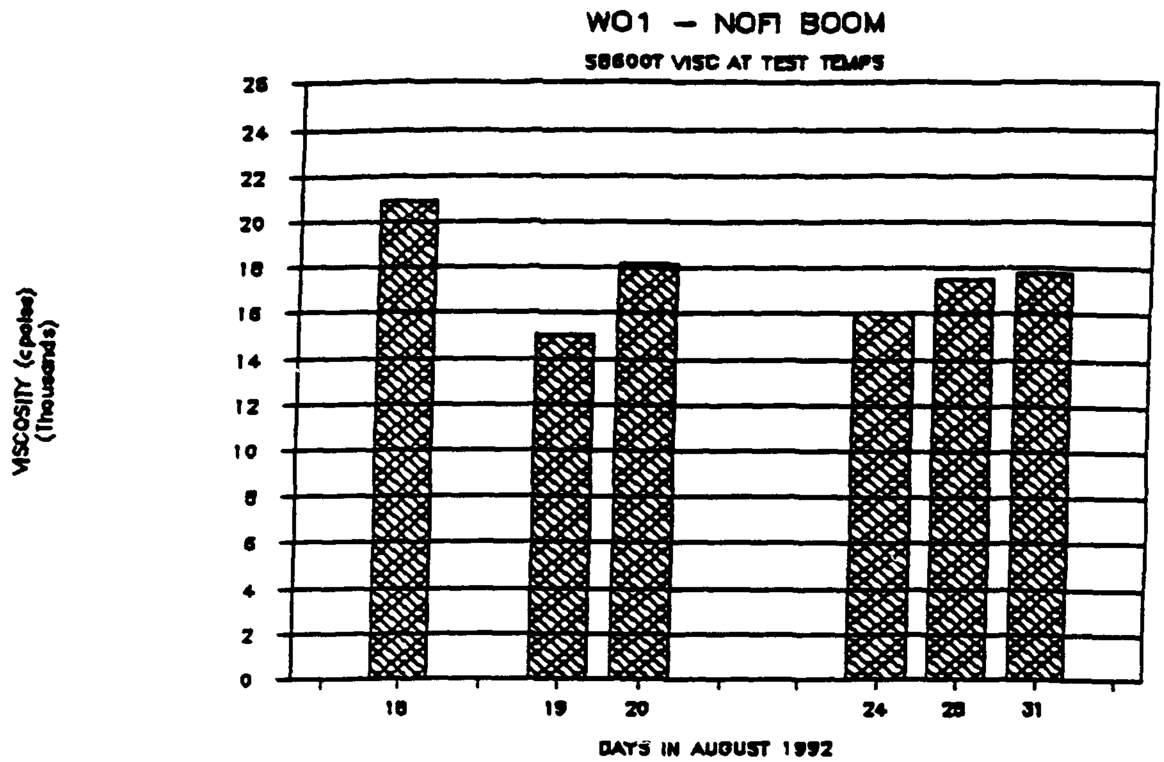
Table C-4. VISCOSITY AT TEST TEMPERATURES DATA

SUNDEX 8600T

DATE IN AUGUST 92	TESTS RUN	AVG TEMP (C)	VISC (cPs)
18	T5B	22.9	20940
	T6A,B		
19	T7A,B	23.1	15040
20	T8B	23.4	18200
	T9A		
	T9B		
24	T11A	25.0	16000
25	T11B	25.0	17500
31	T19A	25.1	17800
	T20A		
	T21A		

HYDROCAL 300

DATE IN SEP/OCT 92	TESTS RUN	AVG TEMP (C)	VISC (cPs)
28	30A1-A4	18.8	575
30	30B	17.1	458
	31A,B		
1	34A,A1	16.1	461
	34B,B1		
6	40A,B	15.3	304
	41A,B		
	44A1,B		



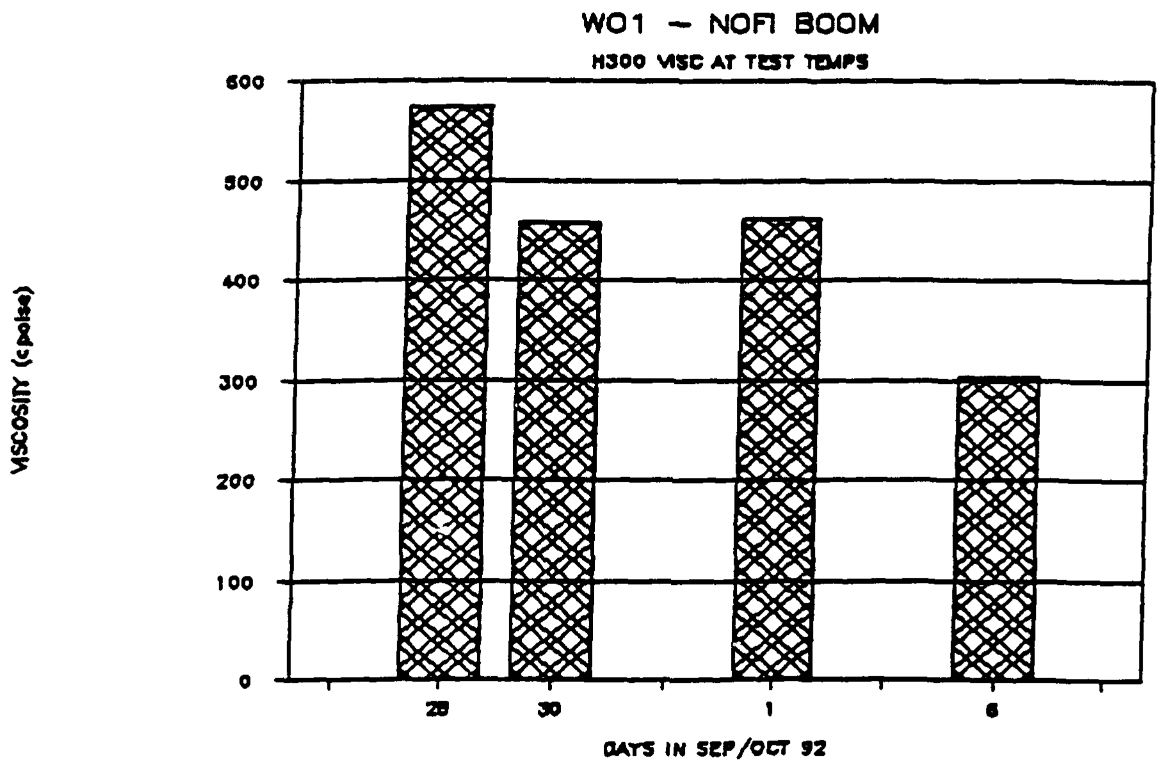


Figure C-5. Graphs of Viscosity at Test Temperature

Table C-5. W01 - NOFI BOOM
WATER AND SEDIMENT IN PETROLEUM

Oil Type	Sample/ Section	Date	Temp (C)	Sample Vol(mls)	%Water	%Sediment
Sundex 8600T	T11A/2	8/25/92		100	40.0	0.40
	/3			100	41.0	0.40
	T11C/5			100	35.0	0.20
	/6			45	17.0	0.10
	T12A/3			100	27.0	0.20
	T12B/1			40	20.0	0.10
	T19A/4	9/1/92		10	45.0	1.00
	/5			8	18.5	0.13
	/6			15	20.0	0.60
	T21A/1	9/1/92	32.0	5	36.0	2.00
	/2			20	30.0	0.50
	/3			25	32.0	0.40
	T23A/1	8/31/92	30.0	50	30.0	0.20
	/2			25	28.0	0.40
	/3			40	37.0	0.25
	/4			40	25.0	0.25
	/5			15	30.0	0.60

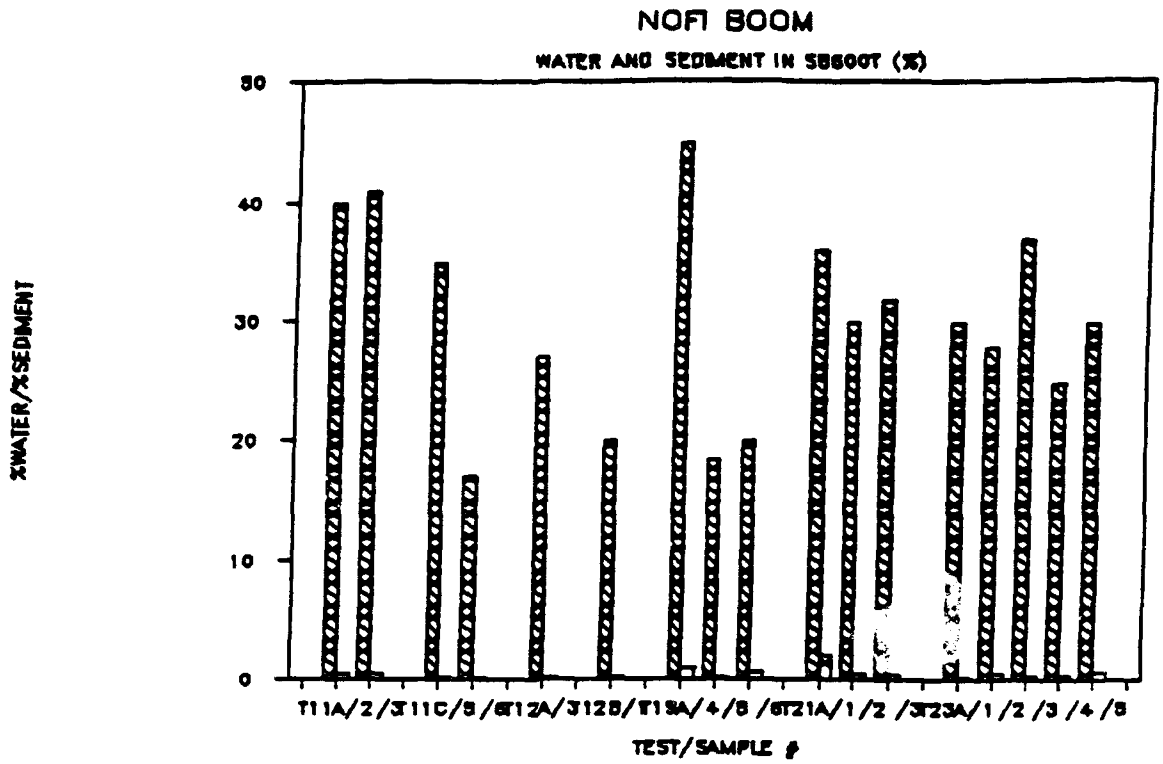


FIGURE C-6. WATER AND SEDIMENT IN PETROLEUM

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APPENDIX D

(The List of Figures is on Page D-25)

INSTRUMENTATION CALIBRATION

OIL/WATER LABORATORY CALIBRATION DATA

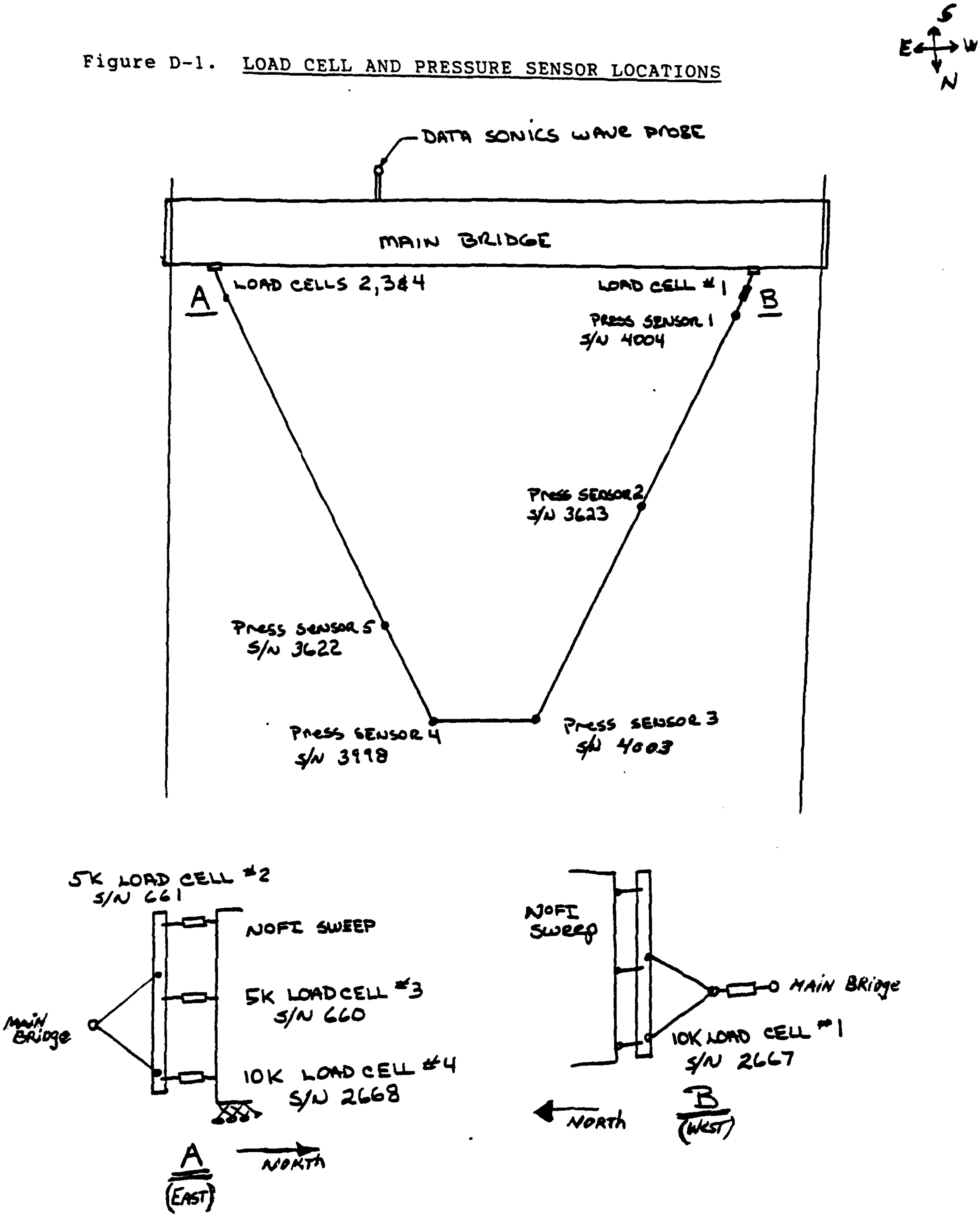
DAILY INSTRUMENTATION CALIBRATION PROCEDURES

At the start and conclusion of each test day, the following procedures were used:

At the start of each test day, we first turned all the equipment on. At the start and end of each test day we recorded all of the instrumentation read outs from the instrumentation panel and noted that they were within the ± tolerances allowed. The instrumentation panel has built-in Calibration and Zero tests. These values were recorded as well. This was an assurance that everything was working properly before and after collecting the test data for the day. The instrumentation checks were also done on the readouts on the Bridge Console and also on the Main Bridge. The power supplies at the Bridge House, the Aux Bridge and the Main Console were also checked and the voltages recorded. This was done for 2 reasons: one was a check that the power supply was turned on and operational and second, that the voltages to power the instrumentation were the correct values. Next the data computer was set up for a 60 second data run to collect sensor information on all of the active data channels. The calibration data runs were done at the beginning of each test day and at the end of each test day. This data was reviewed by the Instrumentation Engineer and the Test Director and/or Test Conductor, at the start and end of the test day.

The video stations (underwater and above water) were turned on during the initial console checkout at the beginning of each test day. When turned on, the camera pictures were checked. The pan, tilt, zoom, iris control adjustments of the cameras were checked. The tape counters were zeroed and the video tapes for the days tests were positioned to the correct tape counter readings.

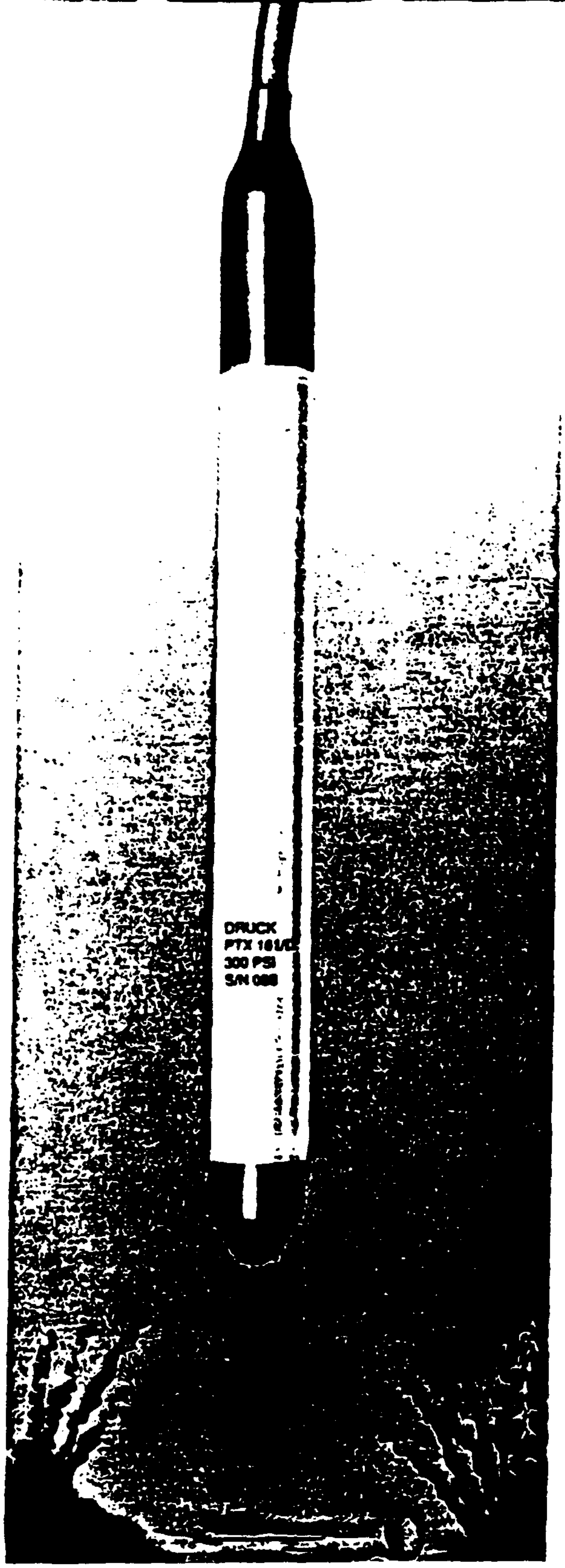
Figure D-1. LOAD CELL AND PRESSURE SENSOR LOCATIONS



PRESSURE SENSOR CALIBRATION PROCEDURE

The individual pressure sensors were put into the tank and lowered and raised to 7 different depth levels. The 4-20 MA sensor outputs were converted to calculated voltage values by using a 220Ω load resistor at the computer console (220Ω x .004MA = .88v and 220Ω x .020A = 4.40v).

A linear regression was done on each set of readings (voltage vs. depth in inches), this gave us the gain and offset value to be used for the computer channels and each data channel was checked for the proper value readout. The calibration sheets are included with this report.



SMALL BORE DEPTH TRANSMITTER

High accuracy
±0.1% BSL for ranges to 2000 ft. water

Totally submersible
With molded integral cable

Excellent overpressure acceptance
<2 times rated pressure

Good thermal stability
±0.3% total error band 30° to 85° F

Titanium construction

Two wire, 4-20mA

The PTX 161/D transmitter has been specifically designed for depth measurement in small bore holes, reservoirs, the sea and many other applications. The 4-20mA operation permits extremely long cable lengths and Druck can supply up to 4500 ft. cable in a single length. The titanium body is electron beam welded, and a polyurethane sheathed cable is molded to the body completing a high integrity waterproof assembly.

The cable is tough, and complete with an integral vent tube and Kevlar strain cord.

The standard accuracy is 0.1% FS (0.06% FS is available) and the new electronic circuit gives very good thermal stability.

Operating pressure ranges

Standard pressure ranges are expressed in psi, gauge or sealed gauge as follows. (Approximate equivalents are also shown for feet of ground water.)

1 psi (2-3 ft. water),
2.5 psi (5.8 ft. water),
5 psi (11.5 ft. water),
10 psi (23.1 ft. water),
15 psi (34.6 ft. water),
20 psi (46.2 ft. water),
30 psi (69.2 ft. water),
50 psi (115 ft. water),
75 psi (173 ft. water),
100 psi (231 ft. water),
150 psi (346 ft. water),
200 psi (462 ft. water),
300 psi (692 ft. water),
500 psi (1154 ft. water),
900 psi (2077 ft. water).

For other pressure ranges, please contact the manufacturer.

Overpressure

The rated pressure can be exceeded by the following multiples causing negligible calibration change:
4 x for 1 psi to 5 psi ranges
2 x for 10 psi range and above.

Pressure media

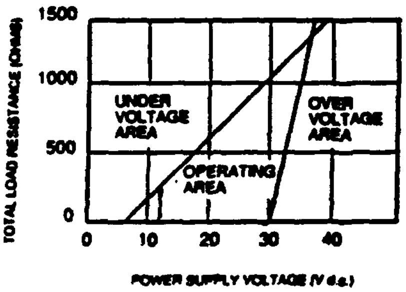
Fluids compatible with quartz and titanium

Transduction principle

Integrated silicon strain gauge bridge.

Transmitter supply voltage

9-30V d.c.
This voltage must appear across the transmitter terminals and the positive supply must be grounded.



For other supply voltages please refer to manufacturer.

Supply sensitivity

0.003% FSO/Volt and excellent 50Hz and 100Hz supply rejection.

Output current

4mA at zero pressure
20mA at full range pressure.

Resolution

Infinite.

Combined non linearity and hysteresis

±0.1% BSL for 1 psi to 900 psi ranges
±0.2% BSL for 1000 to 2000 psi ranges
±0.06% BSL available for ranges to 300 psi on request.

Please refer to manufacturer.

Zero offset

±0.5% FSO set @ 68°F (20°C)

Sensitivity setting

±0.5% of reading, set @ 68°F (20°C)

Operating temperature range

-5° to +140°F (-20° to +60°C)

Temperature effects

±0.3% total error band 30° to 86°F (-2° to +30°C)
1 psi range ±0.5% total error band 30° to 86°F (-20° to +30°C).
For special applications it is possible to give improved temperature compensation over a wider temperature range.

Mechanical shock

1000g for 1ms in each of three mutually perpendicular axes will not affect calibration.

Dimensions

0.69 inches diameter x 8.66 inches length.

Weight

4 oz. nominal

Electrical connection

3 ft. cable supplied as standard. This is molded to transmitter body with polyurethane to provide watertight connection. Continuous lengths up to 4500 ft. can be supplied.

Cable specification:
2 conductor (24 AWG) shielded

- Red	Supply positive
- Black	Supply negative
-Shield	To transmitter body.

Polyurethane outer jacket - 0.285 ins. dia.
Kevlar strength member #29/15000 Denier.
Nylon vent tube
Weight in air, 34 lbs. per 1000 ft.
Weight in water, 6 lbs. per 1000 ft.
Breaking strength, 200 pounds.

Pressure connection

Illustrated front end delrin cone fitted as standard. This incorporates a hydraulic damper to protect the device from high pressure pulses caused by underwater impact.

Pressure connections (optional)

1/4" NPT flat end.
7/16" UNF as MS 33656-4 (1/4 A.N)
Others available on request.

Options available

Pressure transducers type PDCR 830
PDCR 35/D (see separate data sheets).
Pressure connections (see above).

Ordering information

Please state the following
(1) Type number
(2) Pressure range
(3) Temperature range
(4) Cable length
(5) Pressure media

For non-standard requirements please specify in detail.

Continuing development sometimes necessitates specification changes without notice.

Druck Incorporated
4 Dunham Drive
New Fairfield, CT 06812
Telephone: (203) 746-0400
FAX: (203) 746-2494
Telex: 643118

Representative:

PRESSURE SENSOR CALIBRATION DATA
DRUCK S/N 4004 #1

DEPTH inches	Ma	VOLTS
6.75	4.44	0.9768
12.75	4.78	1.0516
18.75	5.12	1.1264
24.75	5.47	1.2034
30.75	5.81	1.2782
36.75	6.15	1.353
42.75	6.5	1.43

Regression Output: current

Constant	4.051383
Std Err of Y Est	0.003273
R Squared	0.999983
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	-0.05720
Std Err of Coef.	0.000103

Regression Output:voltage
Regression Output:

Constant	-70.8238
Std Err of Y Est	0.057222
R Squared	0.999983
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	79.46139
Std Err of Coef.	0.143216

PRESSURE SENSOR CALIBRATION DATA
DRUCK S/N 3623 #2

DEPTH inches	Ma	VOLTS
6.75	4.33	0.9526
12.75	4.68	1.0296
18.75	5.01	1.1022
24.75	5.39	1.1858
30.75	5.72	1.2584
36.75	6.07	1.3354
42.75	6.42	1.4124

Regression Output:current

Constant	3.936428
Std Err of Y Est	0.010141
R Squared	0.999848
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	-0.05809
Std Err of Coef.	0.000319

Regression Output:voltage

Constant	-67.7442
Std Err of Y Est	0.174559
R Squared	0.999848
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	78.22960
Std Err of Coef.	0.430147

DRUCK S/N 4003 #3

DEPTH inches	Ma	VOLTS
6.75	4.43	0.9746
12.75	4.77	1.0494
18.75	5.12	1.1264
24.75	5.47	1.2034
30.75	5.83	1.2826
36.75	6.18	1.3596
42.75	6.51	1.4322

Regression Output:current	
Constant	4.033526
Std Err of Y Est	0.007883
R Squared	0.999908
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	-0.05815
Std Err of Coef.	0.000248

Regression Output:voltage	
Constant	-69.3499
Std Err of Y Est	0.135547
R Squared	0.999908
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	78.15422
Std Err of Coef.	0.333681

DRUCK S/N 3998 #4

DEPTH inches	Ma	VOLTS
6.75	4.38	0.9636
12.75	4.74	1.0428
18.75	5.07	1.1154
24.75	5.42	1.1924
30.75	5.77	1.2694
36.75	6.12	1.3464
42.75	6.46	1.4212

Regression Output:current	
Constant	3.993839
Std Err of Y Est	0.006094
R Squared	0.999944
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	-0.05773
Std Err of Coef.	0.000191

Regression Output:voltage	
Constant	-69.1664
Std Err of Y Est	0.105551
R Squared	0.999944
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	78.72104
Std Err of Coef.	0.261719

DRUCK S/N 3622 #5

DEPTH inches	Ma	VOLTS
6.75	4.38	0.9636
12.75	4.78	1.0516
18.75	5.09	1.1198
24.75	5.44	1.1968
30.75	5.79	1.2738
36.75	6.15	1.353
42.75	6.48	1.4256

Regression Output:current		
Constant		4.009375
Std Err of Y Est		0.018126
R Squared		0.999515
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	-0.05797	
Std Err of Coef.	0.000570	

Regression Output:voltage		
Constant		-69.1100
Std Err of Y Est		0.312579
R Squared		0.999515
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	78.36409	
Std Err of Coef.	0.771706	

LOAD CELL SENSORS CALIBRATION PROCEDURE

The strain gauges were all factory calibrated and a copy of the calibration sheets are enclosed in this report. The calibration data was used to calculate the gain and offset values for the data collection system. A copy of the calculations is included in this report.

DATE 6-19-92

MODEL OR PART NUMBER TL101-10K

DESCRIPTION TENSION LINK

SERIAL NO. 2667

REPAIR ORDER NO. 061601

CUSTOMER MAR INC.

CAPACITY/RANGE 10,000 LBS.

INPUT 10VDC NOM./15VDC. MAX.

OUTPUT 1.836 MV/V

ELECTRICAL CONNECTION:

PIN/WIRE	FUNCTION
1 - CW	+ EXC
2	+ SIG
3	- SIG
4	- EXC

SHUNT CALIBRATION 50 K OHM CONNECTED

FROM PIN 3 TO PIN 4 PRODUCES AN OUTPUT

CHANGE OF 1.745 MV/V WHICH EQUALS 9,504 LBS.

REPAIR REPORT

INSPECTION REPORT FUNCTIONAL

REPAIR REPORT RECALIBRATED

WE CERTIFY THAT ALL CALIBRATION MEASUREMENTS ARE TRACEABLE TO NBS.

UNIT IS FULLY OPERATIONAL.

SIGNED: [illegible] QC MOC SC

DATE 6-19-92

MODEL OR PART NUMBER 2052-5K

DESCRIPTION TENSION LINK

SERIAL NO. 661

REPAIR ORDER NO. 061601

CUSTOMER MAR INC.

CAPACITY/RANGE 5,000 LBS.

INPUT 10VDC NOM./15VDC MAX.

OUTPUT 1.733 MV/V

ELECTRICAL CONNECTION:

PIN/WIRE	FUNCTION
1-CCW	+EXC
2	+SIG
3	-SIG
4	-EXC

SHUNT CALIBRATION 75 K OHM CONNECTED FROM PIN 3 TO PIN 4 PRODUCES AN OUTPUT CHANGE OF 1.166 MV/V WHICH EQUALS 3,364 LBS.

REPAIR REPORT

INSPECTION REPORT FUNCTIONAL

REPAIR REPORT RECALIBRATED

WE CERTIFY THAT ALL CALIBRATION MEASUREMENTS ARE TRACEABLE TO NBS.

UNIT IS FULLY OPERATIONAL.

SIGNED: [signature] QC

MOC FC

D-13

DATE 6-14-72

MODEL OR PART NUMBER 2052-5K

DESCRIPTION TENSION LINK

SERIAL NO. 660

REPAIR ORDER NO. 061601

CUSTOMER MAR INC.

CAPACITY/RANGE 5,000 LBS.

INPUT 10VDC Nom. / 15VDC MAX.

OUTPUT 1.667 mv/v

ELECTRICAL CONNECTION:

PIN/WIRE	FUNCTION
1 CCW	+ EXC
2	+ SIG
3	− SIG
4	− EXC

SHUNT CALIBRATION 75 K OHM CONNECTED FROM PIN 3 TO PIN 4 PRODUCES AN OUTPUT CHANGE OF 1.167 mv/v WHICH EQUALS 3,500 LBS.

REPAIR REPORT

INSPECTION REPORT FUNCTIONAL

REPAIR REPORT RECALIBRATED

WE CERTIFY THAT ALL CALIBRATION MEASUREMENTS ARE TRACEABLE TO NBS.

UNIT IS FULLY OPERATIONAL.

SIGNED: David H. DeGroh QC

MOC FC

DATE 1-17-92

MODEL OR PART NUMBER TL101-10K

DESCRIPTION TENSION LINK

SERIAL NO. 2668

REPAIR ORDER NO. 061601

CUSTOMER MAR INC.

CAPACITY/RANGE 10,000 LBS.

INPUT 10VDC NOM. /15VDC MAX.

OUTPUT 1.840 MV/V

ELECTRICAL CONNECTION:

PIN/WIRE	FUNCTION
1 - CW	+ EXC
2	+ SIG
3	- SIG
4	- EXC

SHUNT CALIBRATION 50 K OHM CONNECTED FROM PIN 3 TO PIN 4 PRODUCES AN OUTPUT CHANGE OF 1.745 MV/V WHICH EQUALS 9,484 LBS.

REPAIR REPORT

INSPECTION REPORT PLASTIC CONNECTOR DAMAGED AND HAS A VERY LOW INSULATION RESISTANCE, (10MΩ) BUT FUNCTIONAL.

REPAIR REPORT REPLACED CONNECTOR AND RE CALIBRATED.

WE CERTIFY THAT ALL CALIBRATION MEASUREMENTS ARE TRACEABLE TO NBS.

UNIT IS FULLY OPERATIONAL.

SIGNED: QC

MOC FC

Load Cell Serial Number	MV Output	2667	661	660	2668	Ma	Volts Across 220Ω Resistor
		Force Values (in pounds)					
	0	0	0	0	0	4.0	0.88
	2	1089	577	600	1087	5.6	1.232
	4	2179	1154	1200	2174	7.2	1.584
	6	3268	1731	1799	3261	8.8	1.936
	8	4357	2308	2399	4348	10.4	2.288
	10	5446	2885	2999	5435	12.0	2.64
	12	6536	3462	3599	6522	13.6	2.992
	14	7625	4039	4199	7609	15.2	3.344
	16	8714	4616	4799	8696	16.8	3.696
	18	9804	5193	5398	9783	18.4	4.048
	20	10893	5770	5998	10870	20.0	4.4
CAL mv		17.45	11.66	11.67	17.45		
CAL Load		9504	3364	3500	9484		

Regression Output:	S/N 2667
Constant	-2723.20
Std. Err of Y Est	0
R Squared	1
Number of Observations	11
Degrees of Freedom	9
X Coefficient(s)	3094.555
Std Err of Coef.	0

Regression Output:	S/N 661
Constant	-1442.53
Std Err of Y Est	0
R Squared	1
Number of Observations	11
Degress of Freedom	9
X Coefficient(s)	1639.248
Std Err of Coef.	0

Regression Output:	S/N 660
Constant	-1499.57
Std. Err of Y Est	0.000030
R Squared	1
Number of Observations	11
Degrees of Freedom	9
X Coefficient(s)	1704.058
Std Err of Coef.	0.000008

Regression Output:	S/N 2668
Constant	-2717.47
Std Err of Y Est	0.000041
R Squared	1
Number of Observations	11
Degress of Freedom	9
X Coefficient(s)	3088.043
Std Err of Coef.	0.000011

TOLKHEIM FLOW RATE METER
(OIL FLOW RATE)
CALIBRATION PROCEDURE

Five test runs were done during the System II Tests using the flow rate meter at five different flow rates. The voltage outputs from the meter (4-20MA across 220Ω resistor) were recorded and used to make a linear regression line. The gain and offset values, to give GPM values on the computer readouts, were then determined. The calculations are included in this report. Measured quantities were compared with calculated values to insure accuracy.

TOLKHEIM FLOW METER CALIBRATION
6/30/92

Regression Output:	12.27488	
Constant	-1.17582	87.26150
Std Err of Y Est	1.949831	151.8413
R Squared	0.999958	396.5864
No. of Observations	5	648.7356
Degrees of Freedom	3	

X Coefficient(s) 411.3364
Std Err of Coer. 1.535934

60 SECOND RUNS TO CHECK ABOVE CALCULATIONS

Recirculate

Flow 630.DAT	Mean Flow	50.1GPM
1 Flow 630.DAT	Mean Flow	123.06GPM
2 Flow 630.DAT	Mean Flow	442.GPM

Pumped out to Recovery Tank

3 Flow 630.DAT	Mean Flow	42.3GPM

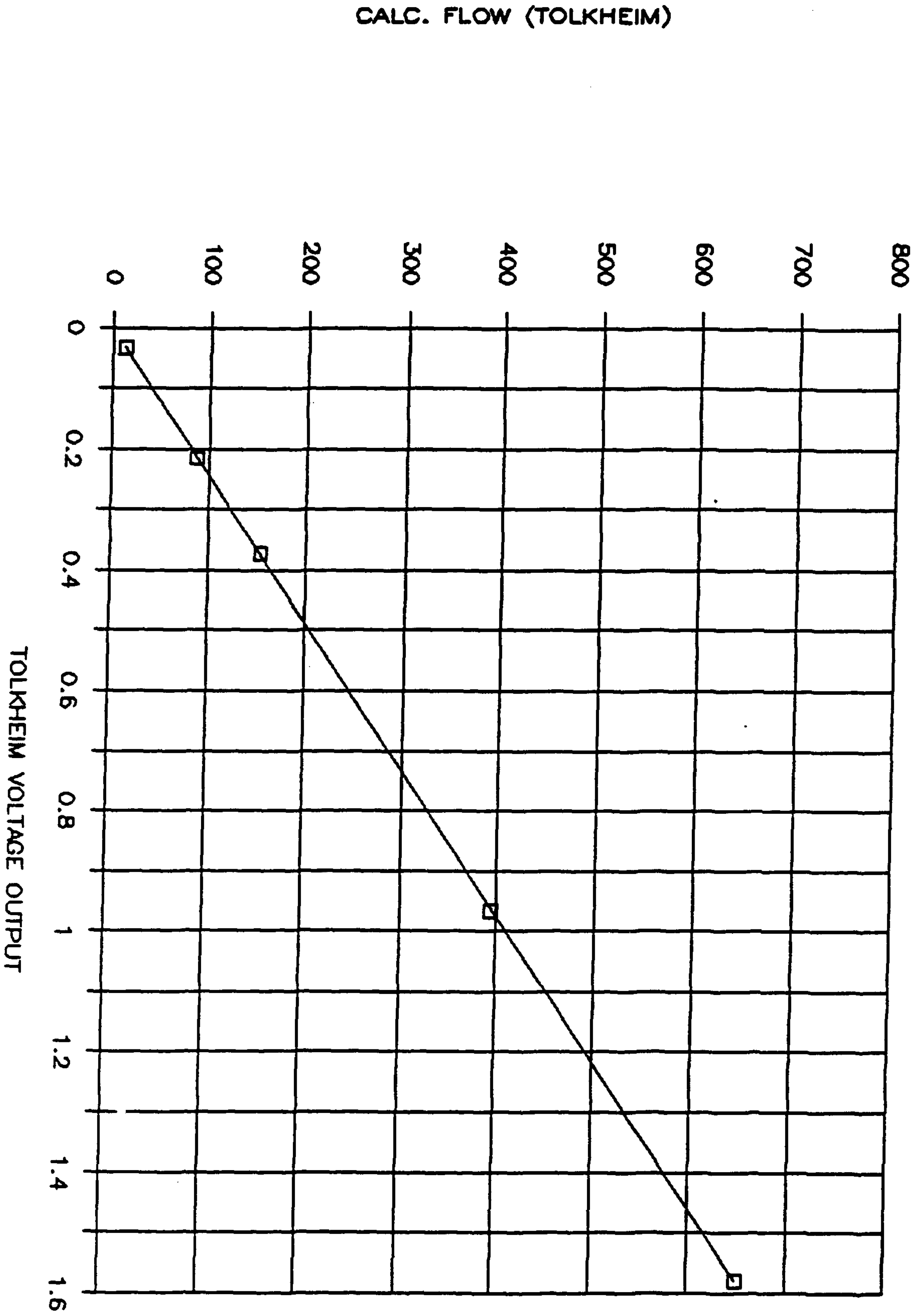


Figure D-2. Tolkheim Voltage Output vs Calc. Flow

Date: 06/29/92 Time: 15:07 A/D Board: DT-2801

Data File: 1FLOW629.DAT Dir: C:\COLLECT\RUN

Run No. 1FLOW Trig Mode: MAN Data Run Length (sec): 60

Comment 1: System 2 Flow rate meter check

Comment 2:

Data Collected at: 10.0000 Hertz

Chan #	ID	EU's	Mean	Max	Min	RMS	Std Dev
3	FLRATE	Voltage	3.27E-2	5.86E-2	0.00E-1	3.48E-2	1.17E.-2

Date: 06/29/92 Time: 15:12 A/D Board: DT-2801

Data File: 2FLOW629.DAT Dir: C:\COLLECT\RUN

Run No. 2FLOW Trig Mode: MAN Data Run Length (sec): 60

Comment 1: System 2 Flow rate meter check

Comment 2:

Data Collected at: 10.0000 Hertz

Chan #	ID	EU's	Mean	Max	Min	RMS	Std Dev
3	FLRATE	Voltage	2.15E-1	2.98E-1	1.66E-1	2.17E-1	3.06E.-2

Date: 06/29/92 Time: 15:16 A/D Board: DT-2801

Data File: 3FLOW629.DAT Dir: C:\COLLECT\RUN

Run No. 3FLOW Trig Mode: MAN Data Run Length (sec): 60

Comment 1: System 2 Flow rate meter check

Comment 2:

Data Collected at: 10.0000 Hertz

Chan #	ID	EU's	Mean	Max	Min	RMS	Std Dev
3	FLRATE	Voltage	3.72E-1	5.03E-1	3.03E-1	3.76E-1	5.00E.-2

Date: 06/29/92 Time: 15:19 A/D Board: DT-2801

Data File: 4FLOW629.DAT Dir: C:\COLLECT\RUN

Run No. 4FLOW Trig Mode: MAN Data Run Length (sec): 60

Comment 1: System 2 Flow rate meter check

Comment 2:

Data Collected at: 10.0000 Hertz

Chan #	ID	EU's	Mean	Max	Min	RMS	Std Dev
3	FLRATE	Voltage	9.67E-1	1.19E0	8.25E-1	9.72E-1	1.03E-1

Date: 06/29/92 Time: 15:21 A/D Board: DT-2801

Data File: 5FLOW629.DAT Dir: C:\COLLECT\RUN

Run No. 5FLOW Trig Mode: MAN Data Run Length (sec): 60

Comment 1: System 2 Flow rate meter check

Comment 2:

Data Collected at: 10.0000 Hertz

Chan #	ID	EU's	Mean	Max	Min	RMS	Std Dev
3	FLRATE	Voltage	1.58V	1.79EO	1.43EO	1.43EO	9.92E-2

OIL/WATER LABORATORY CALIBRATION DATA
CALIBRATION OF MODEL DV-I BROOKFIELD VISCOMETER
May 28, 1992

STD VISC (cps)	ACTUAL VALUE (cps)	SPINDLE NUMBER	RPM	DIAL READING	FACTOR	VISC (cps)
50	44.8	1	12	8.9	5	44.5
			30	22.1	2	44.2
			60	44.6	1	44.6
			30	22.4	2	44.8
			12	9	5	45.0
			60	45.3	1	45.3
			6	4.5	10	45.0
					AVG =	44.8
					STD DEV =	0.341
					RSD =	0.76%
500	474	1	1.5	11.9	40	476.0
			3	23.9	20	478.0
			6	47.8	10	478.0
			12	95.9	5	479.5
		2	6	10.1	50	505.0
			12	20.2	25	505.0
			30	50.4	10	504.0
					AVG =	489.4
					STD DEV =	13.295
					RSD =	2.72%
1000	938	1	1.5	22.6	40	904.0
			3	45.3	20	906.0
			6	91.2	10	912.0
		2	6	19.1	50	955.0
			12	38.2	25	955.0
			30	95.7	10	957.0
		3	30	22.6	40	904.0
			60	45.1	20	902.0
					AVG =	927.3
					STD DEV =	24.749
					RSD =	2.67%
5000	5020	2	1.5	24.3	200	4860.0
			3	48.4	100	4840.0
			6	96.7	50	4835.0
		3	3	12.2	400	4880.0
			6	24.1	200	4820.0
			12	48.1	100	4810.0
		4	30	25.1	200	5020.0
			60	50.1	100	5010.0
					AVG =	4887.9
					STD DEV =	82.974
					RSD =	1.70%

List of Figures